NCR-days 2008

10 years NCR

November 20 – 21

A.G. van Os,
C.D. Erdbrink (editors)

December 2008

Publication of the Netherlands Centre for River Studies
NCR publication 33-2008

ISSN 1568-234X

Abstract

NCR is the abbreviation for the Netherlands Centre for River studies. It is a collaboration of nine major scientific research institutes in the Netherlands, which was established on October 8, 1998. Consequently in 2008 NCR celebrated its 10th anniversary.

NCR's goal is to enhance the cooperation between the most important scientific institutes in the field of river related research in the Netherlands by:

- Building a joint in-depth knowledge base on rivers in the Netherlands in order to adequately anticipate on societal needs, both on national as well as international level;
- Strengthening the national and international position of Dutch scientific research and education;
- Establishment of a common research programme.

NCR strives to achieve this goal by:

- Committed cooperation, in which the actual commitment of the participating parties is expressed;
- Offering a platform, which is expressed by the organisation of meetings where knowledge and experiences are exchanged and where parties outside NCR are warmly welcomed.

The committed cooperation and collaboration is based on a programme. This programme was first published in October 2000 and was actualised in August 2001, August 2004 and November 2006.

The platform function is expressed amongst others by the organisation of the so-called annual NCR-days. The publication at hand contains the proceedings of the NCR-days, organised on November 20-21, 2008.

Since we were celebrating our 10th anniversary the proceedings of the NCR-days 2008 are appropriately subtitled '10 years NCR'.

Samenvatting

NCR staat voor Nederlands Centrum voor Rivierkunde. Het is een samenwerkingsverband van tien wetenschappelijke onderzoekinstituten in Nederland dat op 8 oktober 1998 is opgericht. We vieren dit jaar dus ons 10-jarig bestaan.

Het doel van NCR is het bevorderen van samenwerking tussen de belangrijkste wetenschappelijke instituten op het gebied van rivieronderzoek in Nederland door:

- het opbouwen van een kennisbasis van voldoende breedte en diepte in Nederland betreffende rivieren waardoor adequaat kan worden tegemoet gekomen aan de maatschappelijke behoefte, zowel nationaal als internationaal;
- het versterken van het wetenschappelijke onderwijs en onderzoek aan de Nederlandse universiteiten;
- het vaststellen van een gezamenlijk onderzoekprogramma.

NCR wil dit doel op twee manieren bereiken:

- via *gecommitteerde samenwerking*; hierin komt het daadwerkelijke commitment van deelnemende partners tot uiting;
- via het bieden van een *platform*; deze functie uit zich in het organiseren van bijeenkomsten, waarop kennis en ervaringen worden uitgewisseld; andere partijen zijn daarbij van harte welkom.

De gecommitteerde samenwerking geschiedt op basis van een programma. Dit programma is in oktober 2000 voor het eerst in het Nederlands gepubliceerd en geactualiseerd in augustus 2001, augustus 2004 en november 2006.

De platformfunctie komt onder andere tot uiting in het jaarlijks organiseren van de zogenaamde NCR-dagen. De voorliggende publicatie bevat de “proceedings” van de NCR-dagen die gehouden werden op 20 en 21 november 2008 in Congreshotel Mooirivier in Dalfsen aan de Overijsselse Vecht.

De proceedings van de NCR-dagen 2008 dragen terecht de subtitel ’10 years NCR’.
De verschillende subthema’s van de NCR-dagen 2008, (i) Stroomgebied en Overstromingsrisico management (ii) Hydrologie en (iii) Geomorfodynamica en Morfologie, dekken een groot gedeelte van het hedendaagse onderzoek dat in Nederland op rivierkundig gebied wordt uitgevoerd.

the ladies of Bureau Routine

Preface

The NCR-days are a yearly conference at which mainly young scientists present their ongoing research on a wide variety of fluvial subjects. Since 2000, the NCR-days have been organised in rotation by different institutes represented in the Netherlands Centre for River Studies (NCR). These proceedings are the product of the NCR-days 2008, held on 20-21 November 2008.

The NCR-days of 2008 were special, because this is the year of our 10th anniversary. This time they were organised by Deltares, with the help of the NCR secretariat and Bureau Routine.

The 2008 NCR-days were held in Congreshotel Mooirivier ('beautiful river') along the borders of the Overijsselse Vecht in Dalfsen, the Netherlands. In these inspiring settings, we welcomed some 80 participants.

The first day three keynotes were presented, our well known poster session took place, we had a marvellous excursion along the Vecht through the Vilsteren Estate and started our scientific presentations with Session I, Flood Risk and River Basin Management.
Moreover we celebrated our 10th anniversary in the evening of the first day with an entertaining performance of the group Flater.
The second day started with our second scientific presentation Session II, Hydrology, followed by two parallel Workshops, on Safety in the Delta and Dealing with Droughts, respectively.
In the afternoon the last presentation Session, Geomorphodynamics and Morphology took place and a closing keynote was given by Dick de Bruin.
The NCR-days were concluded, as usual by the awarding ceremony of the NCR-days Presentation and Poster Awards 2008

In total 13 participants gave an oral presentation and 17 posters were presented and discussed.
The contributions (oral presentations and posters) to the conference have been laid down in the more than 30 papers and impressions in this proceedings volume. The papers have been arranged into sections that basically represent the various sessions of the conference.

The organisation of the workshops was in the able hands of Christiaan Erdbrink of Deltares and Bureau Routine.

We wish to thank the chairmen of the sessions Pim Vugteveen (RU), Ton Hoitink (WU) and Marjolein Dohmen-Janssen (UT), and the people giving an introduction at the two workshops: Annemargreet de Leeuw of Deltares, Ilka Tánczos of RWS-WD, Frans van den Berg of Waterschap Rivierenland, Herbert Berger of RWS-WD and Huub Savenije of TUD.
Special thanks is due to the organisers of the excursion, Henk Kloosterboer of Waterschap Groot Salland and Hugo Vernhout of the Vilsteren Estate and to the two chairmen of the workshops Kees Vonk (Waterschap Rivierenland) and Eric Marteijn (RWS-ZH). They succeeded in fostering a very lively discussion in their workshop.

Finally we wish to thank Tine Verheij of Bureau Routine and Jolien Mans of NCR. They saw to all the logistics of the two days and together with Christiaan Erdbrink and Roy Frings provided the photos for these proceedings.

The financial contribution by Deltares and the Netherlands Organisation for Scientific Research (NWO) is gratefully acknowledged.

Over the years, the NCR-days have proven to be an attractive platform for exchange of ideas and discussion within the community of researchers, experts and users of expertise on rivers. The 2008 edition was a memorable example of this.

Huib de Vriend, chairman of the NCR Supervisory Board

Contents

The Overijsselse Vecht and Congreshotel Mooirivier

Introduction

A.G. van Os
NCR, ncr@deltares.nl

The NCR-days are the proof of the pudding of the platform function of NCR: they give all scientists interested in River studies in the Netherlands the opportunity to meet on two consecutive days, to exchange their ideas and research results and to discuss with stakeholders River management issues and the research needs associated with it.

NCR organised these NCR-days for the ninth time on November 20th and 21st, 2008. They were held on the borders of the Overijsselse Vecht in CongressHotel Mooirivier in Dalfsen.

We saw a very varied programme with four Key Note Presentations (pages 4-13, 24-25) an introduction to and subsequent excursion along the Overijsselse Vecht (pages 14-19), our very successful Poster Session (next two pages), two parallel workshops on Safety in the Delta and Dealing with Droughts (pages 24-29) and last but certainly not least three presentation sessions where young researchers presented their ongoing research to an audience of young and experienced colleagues.
The two page papers resulting from these presentations and the posters form the heart of these proceedings (pages 16-17, 30-87).

The NCR Programme Committee decided in 2003 to establish the NCR-days Presentation and Poster Awards. They both consist of a Certificate and the refunding of the participation costs for the NCR-days.
The participants determined the winners. To that end, each participant received four evaluation forms (two for a specific presentation and two for a specific poster) at the registration desk. They were selected at random.

The participants took their ‘evaluation job’ very seriously. In total some 300 forms were returned giving an average of 10 forms per presenter. This added considerably to the liveliness of the discussions during the intermissions and poster sessions.

The poster sessions are a very important part of the NCR-days. We use the ‘Hyde Park Corner approach’ where the primary poster authors are given the opportunity in ‘two-minute-talks’ to give the participants an appetite to come and see the posters and discuss the content with the authors. This worked again very well.
For an impression of this Poster Session see the next pages.
I had the pleasant task to announce the winners of the NCR-days Awards at the end of the NCR-days.

The NCR-days Presentation Award 2008 was won by Arjan Tuijnder of University Twente for his presentation ‘Bedform dimensions under supply limited conditions’ (see page 68).

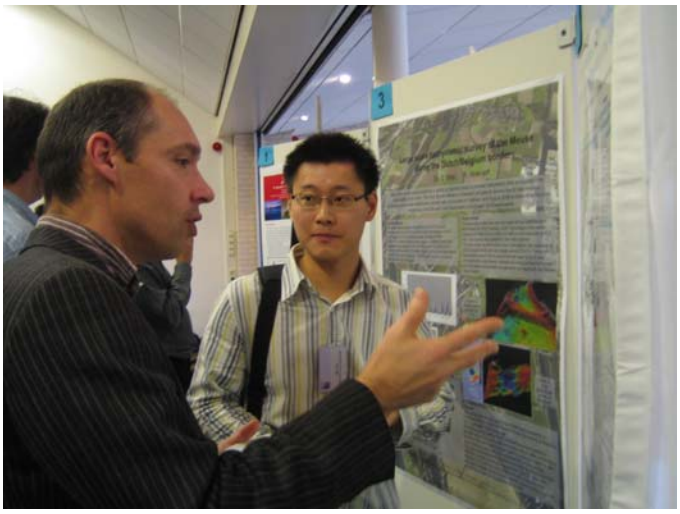
The NCR-days Poster Award 2008 was won by Marta Wozniak of Radboud University and University of Lublin for her poster ‘Landscape change and biodiversity values of the floodplains along the River Vistula, Poland’ (see page 86). The Award was presented to Rob Leuven, because Marta was in Poland happily expecting to deliver her first child any minute.

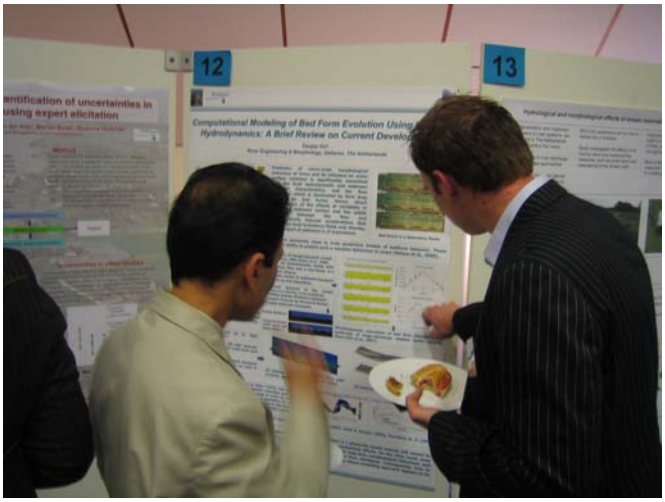
Impression of the Poster Session

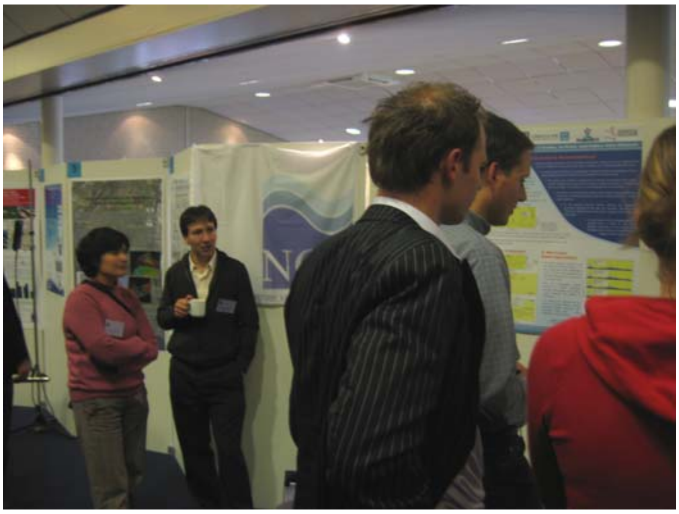


Poster introduction 'Hyde Park Corner style'


the Poster Session


12
13
antification of uncertainties in
using expert elicitation
Computational Modeling of Bed Form Evolution Using
Hydrodynamics: A Brief Review on Current Develop



Key Note: NCR-days 2008; 10 years NCR

A.G. van Os
Programming secretary NCR, Netherlands Centre for River studies, P.O. Box 177, 2600 MH Delft, the Netherlands; ncr@deltares.nl

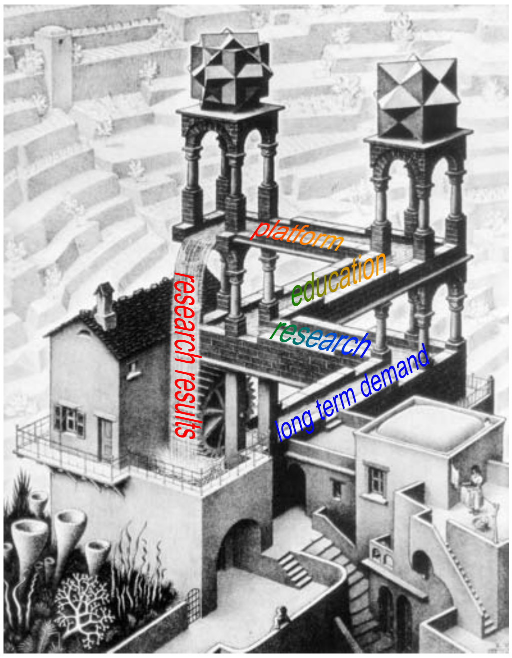
Abstract
The Netherlands Centre for River studies (NCR) is a collaboration of the major developers and users of expertise in the Netherlands in the area of rivers.
The cooperation agreement was officially signed on October 8th, 1998.
In this paper we look back upon 10 years of NCR activities.

the official signing procedure of the NCR Cooperation Agreement on October 8th, 1998

Introduction
Although the cooperation agreement officially was signed in October 1998, the initiative to establish NCR was taken much earlier, to be precise during the now called "pre NCR-days" in 1997 and the spring of 1998 (see also page 7).
Among the founding fathers of NCR were Eric Marteijn of RWS-RIZA, Rivers Department and Eelco van Beek of WL|Delft Hydraulics.

Together with me as "NCR programming secretary elect" we drew up a "Starting Note", a "Global Activities Programme" and a draft Cooperation Agreement. Eric and Eelco were also the first consecutive chairmen of the NCR Programming Committee.
Partners back then were the universities of Delft, Utrecht, Nijmegen and Twente, (Unesco-)IHE, the Staring Centre and the Institute for Forestry and Nature Development, some time later merged into Alterra, RWS, and WL | Delft Hydraulics.
In 2000 TNO joined NCR and in 2003 it was followed by Wageningen University.
As of January 1st, 2008 parts of RWS, TNO and WL | Delft Hydraulics have formed the research institute Deltares. The remainder of RWS stayed on as member of NCR. So, at the celebration of our 10th anniversary we had a total of nine members.

Ambition
NCR's goal is to build a joint knowledge base on rivers in the Netherlands and to promote cooperation between the most important scientific institutes in the field of river studies in the Netherlands to connect the supply of basic and applied research results and the long term needs of the River basin stakeholders. Or in other words: to make the impossible possible.
As a symbol for that we used the world famous etching of M.C. Escher, the waterfall.



Waterfall by M.C. Escher (litho 1961)

We would connect the falling “research results” and the horizontally flowing “long term demand” by the combined

- research
- education and
- platform functions of NCR.

After 10 years we can state that we succeeded in this aim reasonably well.

Research

The research function of NCR was first summarised in Dutch in the “NCR Programma” in 2000 (NCR-publication 01-2000) and in “Summary of NCR Programme, version 2001 – 2002” in 2001 (NCR-publication 05-2001). It was updated in the version 2004 – 2005 (NCR-publication 25-2004). The latest version of this programme is from 2006 -2007 (NCR-publication 30-2006).

It is worth mentioning that NCR is not a funding facility. The partners have committed themselves to put at least the equivalent of some € 100.000 each year into the co-operation, but the real added value of NCR lies in putting together projects that are financed within different research frameworks.
Many of these frameworks provide “shared cost financing” (e.g. EU framework programme or the Bsik programmes like Delft Cluster), meaning that only part of the total costs of the project is funded. Other frameworks (e.g. NWO) only provide financing for University research personnel or instruments.
NCR, being a research co-operation without research funds of its own, provides the platform to bring these frameworks together. Senior researchers of the NCR-partners provide the capacity to analyse the possibilities, to draft the proposals and to supervise the research.

The themes as adopted in our programme are:

- Living (in harmony) with the River ((Over)leven met de rivier)
- River and Floodplain Management
- River Basin Hydrology, including Genesis of Floods, also known as the Hydrological Triangle
- the Morphological Triangle, focusing on bifurcations and high water morphodynamics, including roughness issues.

International role of NCR

A very important part in the NCR-role as far as research is concerned is the building of a strong international image through international research co-operation. This role of NCR started with the EU sponsored (INTERREG-IIC) IRMA-SPONGE research programme that was set up and coordinated by NCR.
The main messages from IRMA-SPONGE in 2002 were:

A. The future brings increasing flood risk.

B. Upstream flood prevention measures can reduce extreme floods only at the local scale.

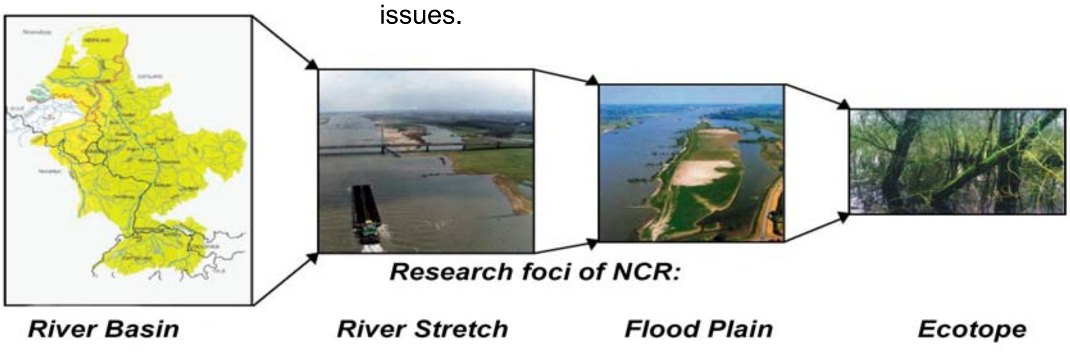
C. The most effective flood risk management strategy is damage prevention by spatial planning.

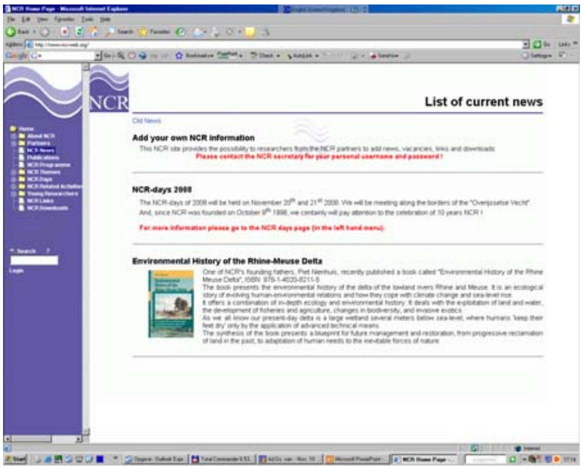
D. Flood risk management strategies should be part of integrated development of the river corridor.

Now in 2008 we can conclude that several of these findings are “rediscovered” by different EU ERA-Net CRUE and other cooperation projects, proving that IRMA-SPONGE really was cutting edge research back in 2002.

The international name of NCR received another boost with the Integrated Project (IP) **FLOOD*site***, a five year (2005 – 2009) lasting project funded by the Global Change part of the 6th Framework Programme of the European Commission.
In this IP eight NCR partners participate and NCR itself plays a co-coordinating role. **FLOOD*site*** held its closing conference in September/October 2008 in Oxford (see Platform function on the next page).

Another follow up of IRMA-SPONGE is the project Freude am Fluss, also recently closed with an international conference, funded by the Interreg IIIC programme of the European Commission and the Dutch research Programme Living with Water.





News page on the NCR website (www.ncr-web.org)

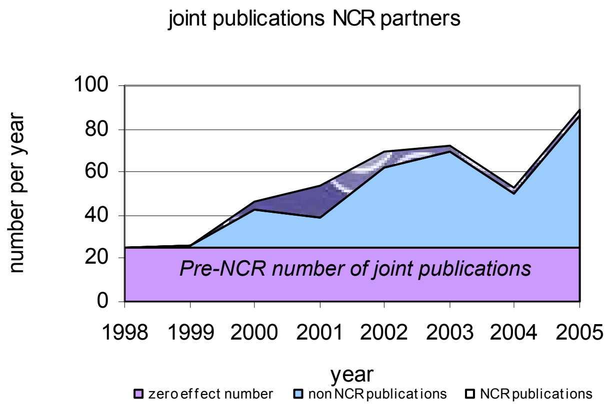
Education
The educational activities of NCR can be summarised by five categories:

1. Preparation of an overview of existing courses on the NCR-web-site (*www.ncr-web.org*)
2. Exchange of teaching staff and (under)graduate students
3. Development of new courses concerning river science and management (e.g. a course on dynamic river management for staff members of the Dutch Ministry of Transport, Public Works and Water Management)
4. Organisation of Thematic Days aimed at young researchers
5. Organisation of Institute Days aimed at students looking for trainee positions or jobs after graduation.

Thematic Days
The Thematic Days are developed and organised by junior researchers of the universities participating in NCR (bottom up activity). The major goals of these days are cross education, strengthening the NCR network and building a common ‘body of knowledge’.
In total some seven thematic days have been organised in the past ten years with subjects as wide apart as “the empirical approach of ecologists and biodiversity of riverine ecotopes” and “bed morphology of large rivers on several time scales” or “demand driven science” versus “Soft Science desperately needed !”.

Institute Days
The Institute Days are being organised yearly by the NCR Programme Committee (top down activity), the large technological institutes (Deltares, Alterra) and the governmental research institute (RWS-WD) participating in NCR. The goal is to give undergraduates and PhD students an overview of (the contents of) the working field of these NCR-institutes, and to facilitate the recruitment of trainees and new staff. A number of participants of 20-30 each year are aimed at. So, within a time span of 4-6 years, each (under)graduate student has the opportunity to participate in the Institute Days.

Platform function
To perform this key function NCR aims to provide an open platform for all people interested in scientific research and communication on river issues.
To that end NCR established an interactive website and started a series of NCR publications.
At the end of this year the NCR publication series will have a total of 33 publications in 39 volumes. The list of these publications is given at the end of this publication (pages 90-91)
Apart from this official NCR publication series, NCR partners also published many papers, conference contributions and other publications together.



In the figure above the number of these joint publications over the years 1998 – 2005 is given. After 1999 a distinct rise in this number is obvious up to some 90 joint publications which is a factor 3,5 increase as compared to the pre-NCR period. We like to call this the NCR-effect.

NCR also (co-)organised a number of symposia and conferences.
Examples of these are:

- the IRMA-SPONGE final Conference January/February 2002, Bonn
- the special session on the 3rd International Symposium on Flood Defences (ISFD3), May 2005, Nijmegen
- the European Conference on Flood Risk Management **FLOOD*risk*2008**, September/October 2008, Oxford, where I had the honour to deliver the closing key note.

NCR-days

Last but certainly not least NCR organises once a year the so-called NCR-days, where on two consecutive days scientists present their ongoing river studies, in order to maximise the exchange of ideas and experiences between the participants and to provide the researchers a sounding board for their study approach and preliminary results. Based on these contacts they can improve their approach and possibly establish additional co-operation.

These NCR-days more or less started in the pre-NCR period with in 1997 and 1998: pre-NCR-days in Lunteren and Delft, where ongoing (university) research was presented. After these events NCR organised in 1999 a workshop with presentations from non-university partners (report in NCR publication series, NCR 02-2000) and then in 2000 followed the first real NCR-days with presentations of ongoing research by "young" researchers (report in NCR publication series, NCR 03-2001).

In 2001 through 2008 we organised yearly NCR-days in November, since 2002 accompanied by a Field Trip in the neighbourhood, (reports in NCR publication series, NCR 07-2001, 20-2003, 24-2004, 26-2006, 31-2007, 32-2007 and 33-2008).

Impression of the NCR-days 2008

Evaluations

At the start of NCR it was agreed to evaluate the functioning of NCR every five years. So, in 2004 the evaluation report for the first five years of NCR was published.

In summary the conclusions were:

- NCR more than succeeded in reaching our common goal
- especially NCR as a network is functioning extremely well
- NCR succeeded in attaining a high profile in European cooperative research.

The Evaluation Committee also gave some recommendations such as:

- the objectives of NCR are OK, but focus also on estuarine stretches of rivers and small catchments
- seek actively dialogue with stakeholders in water management
- continue the NCR-days.

This resulted in an adapted set up of the NCR-days from 2005 onwards were we added parallel workshops to the programme in which the researchers were confronted by and with stakeholder representatives discussing actual water management issues.

The NCR-days of 2008 were no exception on this with our two lively workshops "Safety in the Delta" and "Dealing with Droughts".

In 2008 the second evaluation is taking place. This year saw the establishment of Deltares as a merger of Delft Hydraulics, GeoDelft, TNO Built Environment and parts of RWS-RIZA, RWS-RIKZ and RWS-DWW and the forming of RWS Water Service (RWS-WD) as a merger of the remaining parts of RWS-RIZA, RWS-RIKZ and RWS-DWW.

Moreover in August 2008 the report of the new Dutch Delta Committee was published giving a lot of thought as far as research in the fields of NCR is concerned.

Both developments combined give a very good opportunity for NCR to formulate a new research programme focused on the fresh water management in the Netherlands.

Conclusion

Looking back on 10 years NCR we can conclude with the 2004 Evaluation Committee that NCR more than succeeded in the goals of 1998.

NCR has gained a very good name in the European Flood Risk Management research community.

The NCR-days have been very successful over the years with a lot of enthusiastic young and experienced participants.

So, now that I myself am leaving NCR as programming secretary, I can state that NCR has won itself a strong position in the Dutch and European River research world. I will cherish the memory of NCR (on my NCR memory card) and I wish NCR all the best in the near future.

Memory card distributed at the end of the NCR-days 2008

Key Note: Recommendations of the Delta Committee; a living land builds for its future

B.W.A.H. Parmet
Ministry of Public Works, DG Water, Secretary of the Delta Committee, the Netherlands; bart.parmet@minvenw.nl

Abstract
The Delta Committee has been asked by the government for advice on how to arrange the Netherlands so that our country can be protected against flooding over the very long term, while still remaining an attractive place in which to live. Furthermore, the Committee has been asked to look at consequences extending further than safety alone. It has also been asked to investigate possible synergy with other societal functionalities, such as places of residence and work, agriculture, nature, recreation, infrastructure and energy.

Given the state of a number of diked areas, the safety issue is urgent right now and, with rising sea levels, greater variation in river discharge, and a further growth of interests that need protecting, it will only become more so. A disastrous breach in a dike anywhere in the country can disrupt the entire country.
The current legal standards date from the 1960s. Currently about a quarter of all flood defences do not comply with the present standards, while the compliance of a further 30% is uncertain.
In the Delta Committee's view we should anticipate a sea level rise of 0.65 to 1.3 meters in 2100 and from 2 to 4 meters in 2200. This includes the effects of land subsidence. These values represent possible upper bounds; it is sensible to work with them so that the decisions made and the measures adopted will be sustainable over the long term, set against the background of what we can possibly expect.
Rising temperatures and possible changes in air circulation patterns will lead to declining summer discharges and increasing winter ones in the Rhine and the Meuse basins. There is a limited discharge capacity for the Rhine in Germany, which means that the upper Rhine discharge limit that the Netherlands can expect around the year 2100 may reach 18,000 m^3/s. For the Meuse we should anticipate a design discharge of at most 4,600 m^3/s around 2100.
Water intake and with it the country's fresh water supply come under pressure when the sea level rises and salt water penetrates further inland via the rivers and ground water,. Dry summers, like in 2003, will occur more frequently, leading to damage to agriculture and shipping. Other economic sectors will also be harmed as a result.

A coherent vision and a national perspective
It is the Committee's view that all of the Netherlands must remain an attractive country in which to live, work, invest and recreate. The two pillars on which the strategy must rest in the coming centuries are safety and sustainability.
Water safety is of utmost importance to the whole of the Netherlands. A safe delta is a collective societal good for which the government is and will remain responsible. It is upon this collective societal interest that the principle of solidarity is based: everyone contributes to water safety since everyone has an interest in a safe Netherlands, both now and in the future.

Innovative approach to risk
The Committee has remained true to the risk management approach that the first Delta Committee elevated to a principle. On top of this, however, the new Delta Committee has paid explicit attention to reducing the probability of fatalities, while maintaining a

broad definition of the concept of safety, where damage involves more than just economic harm.
The safety level of various diked areas must be assessed based on three elements:
1. The probability of fatality due to flooding. A human life is worth the same everywhere and the probability of a fatality due to a disastrous flood must therefore be assessed on a common basis, to be agreed throughout society. The Committee proposes a probability of one per million,

which is comparable with other (external) safety risks, such as those associated with industrial plants and the transport of hazardous materials.

2. The probability of large numbers of casualties in a single flood episode. This probability is currently far greater than all other external safety hazards combined. The Committee finds this unacceptable. There is as yet no measure for the 'societal (group) risk' due to flooding. It is the Committee's urgent advice that such be developed as soon as possible.
3. Possible damage, involving more than economic harm alone. It is the Committee's view that damage to the landscape, nature and cultural-historical assets, social disruption and a harmed reputation must be explicitly incorporated.

In combination, these three elements result in a single, amended standard for water safety.

Water safety highest priority

Our insight into the way these three elements can be combined into a new standard is not yet complete. It needs further refinement. The Committee believes, however, that safety levels should not be determined purely on the basis of calculations. After careful consideration, it is the Committee's judgement that the present safety level for all diked areas must be improved by a factor of at least 10. In the Committee's view, further refinement leading to a factor lower than 10 can be justified only on very substantial grounds. In view of the considerable likelihood of large numbers of casualties, the Committee rather expects that further refinement will lead to a still higher factor for a number of diked areas, to improve safety yet further. The Committee has considered the concept of Delta Dikes for such diked areas.

A sustainable strategy ...

The Committee considers that safety comes first. The solutions that the Committee proposes, though, make a substantial contribution to the physical quality of the Netherlands and thereby to its attractiveness as a location to live and work.
The Committee's proposals:

- are to harmonise as far as possible with natural processes: 'building with nature and other ecological processes';
- are as far as possible integral and multifunctional; solutions deliver added value to society;
- are cost-effective;
- are flexible and can be implemented gradually to take advantage of long-term developments;
- contain prospects for action in the short term;
- are rooted in Dutch tradition and can serve as a beacon to the rest of the world.

The Committee emphasises that government must remain responsible for climate-proof arrangements. The advice also offers room for active market involvement: where possible, private parties may be invited to co-invest in sustainable arrangements for the Netherlands, especially where investments in water safety are accompanied by the reinforcement of other interests and values, such as nature, recreation, industry, agriculture, infrastructure, energy and housing.

... for the entire Netherlands

The Delta Committee has arrived at a number of recommendations for a *Delta Programme*, which demands a coherent, comprehensive package of investments running over more than a century. These recommendations ensure that the Netherlands can absorb the effects of climate change while still remaining an attractive, safe country over the long term. In this regard the Committee has made choices based on a view of the nation as a whole, tested against an overarching national interest, to which factional interests are subservient.
The Committee's point of departure is our present, interlinked water system with the associated arrangements that allow it to serve a variety of functions. At the same time, the short and medium-term recommendations in this advice have been chosen so that different options will remain open over the longer term. This allows future generations to form their own judgements, based on their own insights and values. Flexibility is essential: it is important to stay abreast of developments, to keep our knowledge up to date, continually assessing our plans and modifying them where necessary.

The Committee distinguishes between three time horizons and has set its recommendations in that context:

- concrete measures in the period until 2050;
- a clear vision towards 2100;
- opinions on the very long term, beyond 2100.

Safety level

The backlog of work needed to make the flood defences in the Netherlands comply with present safety standards must be remedied quickly. This also holds for setting new water safety standards, so that the present safety level will be improved by a factor 10. New standards can be set before 2013. The measures needed to increase the safety level must be implemented before 2050. These must take account of the predicted sea level rise and increased river discharges, as well as the Delta Committee's long-term vision. The Committee stresses the importance of combining water safety with the exploitation of opportunities for nature, housing, agriculture and other activities.

Plans for the construction of new buildings

The Committee does not recommend an unequivocal ban on building on physically unfavourable locations. Space is scarce, after all. Decision making on planned new building in these areas (on weak peat lands, for instance) must be based explicitly on an integral cost-benefit analysis. The costs arising from local decisions must not be passed on to another administrative tier, nor to society as a whole; rather, should they be carried by those who profit from them.
This principle must be incorporated into the wider context of decision making on climate policy, which can be applied regionally and locally. Water managers must become involved in this process at an early stage.

Areas outside the dikes

New development in areas outside the dikes must not impede the river's discharge capacity or the future levels of water in the lakes. Residents/users themselves are responsible for such measures as may be needed to avoid adverse consequences. Government plays a facilitating role in such areas as public information, enquiries and warnings.

North Sea coast

For the North Sea coast (Holland, the Zeeland headlands and the Wadden Islands), the emphasis lies on maintaining coastal safety by continuing the practice of beach nourishments, which will offer permanent safety until far into the next century. The Committee advises that nourishments must be carried out in such a way that the coast can grow already this century to meet the needs of society. This vision should allow the 'weak links' to be dealt with. A growing coast in fact creates extra space for nature and recreation (including seaside resorts). Islands off the coast have a beneficial effect on coastal safety, albeit only a limited one compared with beach nourishments. They can be constructed for other functions, but coastal expansion is more cost-effective for nature and recreational functions.

Wadden area

Large-scale beach nourishments along the North Sea coast have a beneficial effect on the Wadden area, allowing it to grow with rising sea levels. Developments in the Wadden area must be observed with care. The sea defences in the Northern Netherlands and the Wadden Islands will be brought up to strength and maintained.

South-western Delta

The Committee can see good arguments – primarily ecological ones – for completely restoring the tidal dynamics in the Eastern Scheldt when the life-span of the Eastern Scheldt storm surge barrier can no longer be extended, which is expected between 2075 and 2125. A solution must be chosen in good time, because if a completely open variant is selected, then the flood defences around the Eastern Scheldt must be brought up to strength. To maintain the estuarine character the sand starvation in the Eastern Scheldt must be tackled by sand nourishments in the short term.
The Western Scheldt must remain open to preserve both the valuable estuary and the shipping lane to Antwerp. Safety must be maintained by dike reinforcement.
The Krammer-Volkerak Zoommeer lake, combined with the Grevelingen, must be arranged to store large quantities of river water temporarily when river discharge is high. A fresh-saline gradient in the lake will rapidly improve water quality. The water supply from the South-western Delta for agriculture and industry must be guaranteed by fresh water supplied from the Hollands Diep. When the details of this plan are developed further, the Committee's advice is to investigate whether water pricing may be applicable.

River area

In the short term it is imperative for the river area that the programmes *Room for the River* and *Maaswerken* be implemented. For the time being, the Committee assumes that the maximum discharge that can reach the Netherlands via the Rhine is 18.000 m^3/s. The design discharge for the Meuse is 4.600 m^3/s in 2100. It is essential to harmonise measures with neighbouring countries under the European *Directive on the assessment and management of flood risks*. It will be necessary to reserve the space needed to accommodate these maximum flows, possibly by establishing a permanent preference right and, if necessary, by strategic land acquisition. The peak discharges expected in 2100 must be anticipated, if possible, before 2050 for both the Rhine and the Meuse.

Rijnmond
The Committee recommends studying the 'closable-open' variant for the Rijnmond area immediately: the area can be closed off by barriers when faced with extremely high water levels. This offers safety, while at same time allowing the development of attractive living environments (city water fronts) and nature reserves. A 'closable-open' variant needs the Maeslant and Hartel Barriers, and the Haringvlietdam with its sluices (all of which will need replacing between 2050 and 2100), possibly supplemented with other closable barriers on the Spui, Oude Maas, Dordtse Kil and Merwede.
Salt intrusion via the Nieuwe Waterweg will no longer be counteracted with large quantities of river water. The fresh water supply for the Western Netherlands will be drawn mainly from the IJsselmeer lake and local storage where possible. The Committee recommends that this be implemented before 2050. The fresh water supply to the Rijnmond area, including possible innovative water management options, must be incorporated into studies of the 'closable-open' approach.

IJsselmeer area
The Committee has opted for a water level rise of at most 1.5 m in the IJsselmeer lake. The importance of the strategic fresh water reserve and the need to be able to discharge into the Wadden Sea without pumping for as long as possible are more important, in the Committee's view, than the disadvantages (extra costs) of the increased water level. Related to expected climate change, from 2050 onwards, a 'water slice' of 1.5 m will be needed in the IJsselmeer in years of extreme drought. A water level rise of more than 1.5 m would have significantly adverse effects on safety in the lower reaches of the IJssel and the Zwarte Water, which is why the Committee advises a maximum 1.5 m water level rise to afford the greatest possible flexibility. A phased approach may be adopted, but the aim must in any case be to have the largest possible fresh water reserve available around 2050.
The water level in the Markermeer will not be raised. A clearly defined water level offers clarity for urban development in Amsterdam and Almere. After the safety backlog has been remedied, the flood defences, with their prized landscape along the coast of North Holland, will not need to be reinforced again.

Cost
Implementation of the *Delta Programme* will require a sum of 1.2 to 1.6 billion Euros per annum until 2050, and 0.9 to 1.5 billion per annum between 2050 and 2100. Under the *Delta Programme* coastal safety will be maintained by means of beach nourishments. Extra nourishments to expand the coasts of Holland and the Zeeland area into the North Sea by 1 km, for instance, and thus to create space for such functions as nature and recreation, will require an additional 0.1 to 0.3 billion Euros per annum. These sums are merely an indication. New insights may lead to different measures, with cost implications.

Funding and implementation
The Delta Committee indicates that the measures it advises will impact the arrangement and the use of physical space throughout large areas of the country. The Committee's proposals will have consequences at a variety of scales and will thereby impact many functions and interests. Improving water safety –protection from flooding and water nuisance, and securing the fresh water supply – forces choices about land use and therefore touches the development of agriculture and nature, urban development, infrastructure, shipping, ports and other sectors of the economy. Implementation of the *Delta Plan,* therefore, demands an integral, harmonised interface with other facets of spatial planning, touching such aspects as the economy, energy, nature and landscape, etc. The need for such an integrated approach leads the Committee to urge the appointment of a ministerial steering committee led by the Prime Minister. Final political responsibility for implementation and execution remains with the minister of Transport, Public Works and Water Management.

The political-administrative organisation can be further reinforced by the appointment of a Delta Director who can serve as secretary to the ministerial steering committee and thus assure horizontal and vertical communication. The Delta Director will translate the national task into regional ones. Responsibility for development and implementation of the regional tasks would generally rest with the regional administrators. In practical terms, the committee advises the use of the water managers' experience and expertise. Finally, the Delta Committee proposes that a permanent, dedicated Delta Theme committee be instituted in the Parliament to assure parliament's supervision of the *Delta Programme's* implementation and execution.
The measures the Committee proposes are so important for our nation's water safety and fresh water supply that their financing must be independent of short-term political priorities and economic fluctuations. The Committee's advice, therefore, envisions the institution of a Delta Fund, to be supplied from (part of) the natural gas profits and long-term loans.
Those political-administrative and financial recommendations that are not already set down in current legislation will be anchored in a new *Delta Act*.
The Delta Committee emphasises the importance of society's close involvement with the water safety in our country. The necessary approach to flood protection and a sustainable fresh water supply can be realised only if society at large – residents and industry – is careful with and aware of the way it uses water.
The *Delta Programme* must be a sustainable one, which the Committee interprets as an enduring attempt to use water, energy and other basic materials as efficiently as possible to preserve and even improve the quality of the living environment. The Committee can see innumerable opportunities, the key concept being multifunctionality. Biodiversity can flourish if we offer more room for the dynamics of the sea and rivers. Residential environments (suitably adapted) can be created in water storage areas, on new land or on Delta dikes. Development and utilization of sustainable energy supplies near or with the water can simultaneously cut greenhouse gas emissions while combining functionalities.

And now to work!

There is a great deal on our path and it is no use closing our eyes to it. But we have the means, the knowledge and the time to take up the challenges and grasp the opportunities. That we have the time does not mean that we can wait. With the Delta Committee's advice in hand, the Netherlands must set to work today: not just on the coast and along the rivers, but also around the seat of government in the Hague and everywhere in the country where politicians, administrators, professionals and scientists are working on water safety and shaping the Netherlands.

Key Note: Internationalisation of river development

D. de Bruin
retired senior officer of Rijkswaterstaat, Department International Relations
dick.debruin@hetnet.nl

Summary by D. de Bruin and C.D. Erdbrink
Deltares, section of River dynamics and inland water transport, christiaan.erdbrink@deltares.nl

Since the last decades, the development of natural waterways, in particular the main cross border rivers, shows more and more approaches and solutions of human intervention schemes that are no longer specific and typical for one single country, but that can be characterized as common interventions on a basin wide scale; in fact they show cross border uniformity. It is the result of recent developments in international cooperation, R&D, IT, communication and politics.

Here are some of the aspects of international river projects that were highlighted in Dick de Bruin's key note speech:

- coordination and management
- financing of implementation schemes
- additional requirements formulated by financing organisations
- export of know-how
- public information

In this key note attention was given to a broad spectrum of issues that currently play a role in the so-called internationalization of river development. This was done as a kind of slide show presentation: a random power point presentation of appealing issues, being (well known) elements in that spectrum.

Dick de Bruin delivered a very lively presentation based on professional and personal experiences. The slides showed a part of his extensive collection of photographs reflecting all kinds of hydraulic projects of various ages and of all parts of the world. This kaleidoscopic view made for an interesting and inspiring conclusion of the NCR days 2008.

The Overijsselse Vecht

Since the location of the NCR-days 2008 was along the borders of the Overijsselse Vecht we thought it appropriate to pay some special attention to this river.

This was achieved by presentations by Susanne Groot from HKV Consultants

and
Henk Kloosterboer from
the Water board Groot Salland.

Subsequently Hugo Vernhout, director-steward of the Vilsteren Estate gave an introduction to this estate, followed by an entertaining excursion over the Vilsteren Estate.

Excursion along the Overijsselse Vecht

After the introduction by Hugo Vernhout, director-steward of the Vilsteren Estate (see pages 18-19) we left the Conference premises to walk to the nearest weir in the Vecht.

Here three covered wagons waited to bring us into the heart of the Vilsteren Estate.

We left the wagons to listen to an ardent speech from Hugo Vernhout regarding the pros and cons of reconnecting the meanders on the Vilsteren estate to the Vecht River.

Then Hugo led us along a small footpath to the "corkscrew"

and the "tea pavilion".

At the end of the walk we were met by the covered wagons. They brought us to the village of Vilsteren

and eventually dropped us off at the weir.

Hydraulic consequences of connecting meanders to the Vecht

S. Groot, P. Termes
HKV Consultants, P.O.Box 2120, 8203 AC, Lelystad, the Netherlands, groot@hkv.nl

Abstract
The hydraulic consequences of reconnecting three old meanders near Varsen and Vilsteren to the Overijsselse Vecht are studied. The main channel of the Vecht will be maintained, especially for discharge capacity during floods. Flow conditions in the meanders and in the Vecht channel should remain within certain boundaries, to create favourable conditions for ecology. To force water to flow trough the meanders (instead of the much shorter and less rough Vecht channel), barriers have to be constructed in the Vecht. However, navigation on the Vecht has to remain possible and flood water levels should not rise. A Sobek RE model is used to study different designs by determining effects on water levels, discharges and flow velocities. It shows that by connecting the meanders and shallowing the Vecht, the desired discharge distribution can be approached, while keeping flood water levels low and the Vecht navigable. However, due to morphological activity, the meanders, as secondary channels, will not be stable. A semi-natural ‘living Vecht’ in the present-day landscape should be well controlled.

Introduction
Until normalisation around 1900, the Overijsselse Vecht was a dynamic meandering river, with high morphological activity. However, to improve navigability and control sedimentation and erosion, in the 20th century meanders have been cut off and weirs were built. Now, in the framework of the ‘living Vecht’, water boards, the Province of Overijssel and other parties involved are investigating the possibilities of reconnecting old (partly) still present meanders to the Vecht.

The Overijsselse Vecht is a rainwater river, with a catchment area of 378.000 ha of which half is in Germany. The length of the Vecht from Emlichheim at the German border to the outflow in the Zwarte Water is about 60 km (90 km before meanders were cut off). The discharge can vary between a summer low of 2 m^3/s to 250 m^3/s at Emlichheim and 500 m^3/s at Dalfsen. The study area is located just upstream of Dalfsen, between weir Junne and weir Vilsteren. Three old meanders are present here (see Fig. 1):

1. south meander at Vilsteren, still present with a downstream connection to the Vecht
2. north meander at Vilsteren, not present as open water, but visible in DTM
3. meander at Varsen, present as a lake with a higher water level than the Vecht.

Figure 1. Aerial photograph of the Overijsselse Vecht with old meanders at Vilsteren and Varsen still present

Study
Based on a quick scan, scenarios are defined to connect the meanders. The most feasible scenario is presented here:

- connect two meanders near Vilsteren
- keep meander at Varsen unconnected
- keep Vecht as navigation and flood channel
- remove bank protection of the Vecht where possible between weirs Junne and Vilsteren
- build constructions in the Vecht to direct discharge into the meanders, if necessary.

The Vecht will remain the main channel, to ensure enough capacity at high discharges and to enable navigation up to Ommen. The main function of the meanders is ecological. They should represent the KRW water type R6 (Stowa, 2006), meaning they should have a discharge between 0.4 and 7.4 m^3/s, with flow velocities between 0.2 and 0.5 m/s.

The existing Sobek RE model of the Dutch part of the Vecht (Udo and Termes, 2003) is adapted to represent the described scenario. Calculations are made to determine water levels and flow conditions for a range of discharges (from stationary discharge exceeded 80 days/year up to a dynamic discharge with return period of 100 years including climate change).

Results

Without structures in the Vecht to direct discharge into the meanders, the meanders have very low discharges and flow velocities. The Vecht channel remains dominant, because:

- length of the meanders is 1.7 and 2.8 times the length of the Vecht
- flow profile of the meanders is about half the size of the flow profile of the Vecht
- hydraulic roughness of the meanders is higher than that of the Vecht

Water preferably flows trough the Vecht channel. To direct water into the meanders, two options are studied: barriers in the Vecht just downstream of the inflow and shallowing of the Vecht channel (Fig. 2). Both structures are meant to heighten water levels at the inflow of the meanders to increase the slope of the water table.

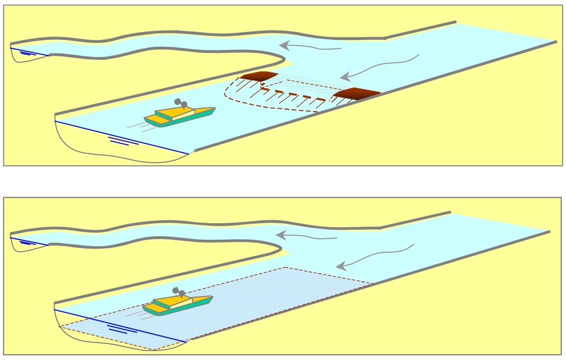


Figure 2. Two options to direct discharge trough the meander

Fig. 3 gives the resulting calculated flow velocities in the meanders. Even with the weirs or the shallowing (of which dimensions are optimised to permit navigation and direct discharge), the flow velocities drop below the R6 boundary at 1/4Q. This means that during long periods (>280 days/year) flow conditions are not optimal for ecology. The barriers give much obstruction, creating very high flow velocities during the more extreme events (1Q, T100). Water levels during high discharges are increased by the structures (see Table 1). The shallowing is the better option for the ecology, but does result in an increase in water level.

The bifurcation points of the meanders will probably not be stable (following Wang et al, 1995 and Mosselman, 2001). This probably means that the meanders, as secondary channels, will fill up with sediment. To keep the meanders open, structures to retain the sediment in the Vecht channel (e.g. 'Bulle-krib') or dredging can be applied. The new meanders and the Vecht channel are allowed some dynamic activity, including horizontal movement of the channel. Based on historical meander development along the Vecht, the movement is expected to be less than 1 m/year.

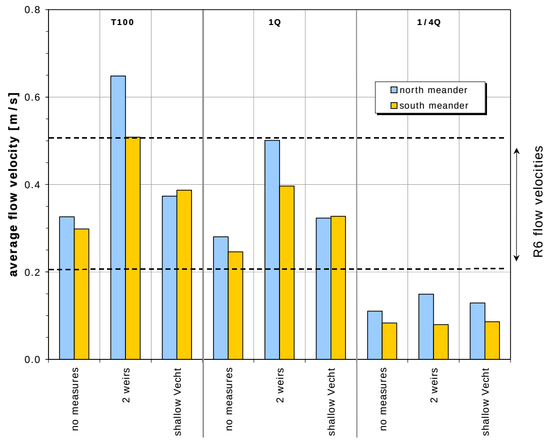


Figure 3. Average flow velocities in the meanders

Table 1. Change in water level in the situation with meanders compared to the reference situation

change in water level [m]	T100: 1/100 year dynamic discharge	1Q: discharge exceeded 1 day/year
no structure	-0.02	-0.01
barriers (weirs)	+0.15	+0.13
shallowing	+0.01	+0.04

Conclusions

It is possible to connect meanders to the Vecht; a semi-natural river is technically feasible. The meanders will need maintenance and possibly structures have to be applied to direct discharge and/or sediment. The meanders will create a more dynamic and varying ecosystem and dynamic activity of the Vecht is, although limited, allowed. The flow conditions and morphological activity should be monitored.

It proofs to be difficult to meet all restrictions and wishes of a 'living Vecht'. Choices have to be made between (a combination of) safety, ecology and navigation -and costs.

References

Mosselman, E. (2001) Morphological development of side channels, WL Delft Hydraulics, Delft, the Netherlands.
Stowa (2006) Referenties en maatlatten voor rivieren ten behoeve van de kaderrichtlijn water. Update 2006. Stowa-rapport 2004-43, the Netherlands.
Udo J., A.P.P. Termes (2003) Uitbreiding SOBEK-River model Vecht. Het IJssel en Vechtmodel, HKV LIJN IN WATER, Rapportnr. PR387/PR606, Lelystad, the Netherlands.
Wang, Z., R. Fokkink, M.D. Vries, A. Langerak (1995) Stability of river bifurcations in 1D morphodynamic models. Journal of Hydraulic Research, 33(6), 739-750.

The estate of Vilsteren

H. Vernhout
Landgoed Vilsteren, the Netherlands, info@landgoed-vilsteren.nl

The Vilsteren Estate and village are situated on the southern bank of the River Vecht. The earliest settlements appeared here on the border between the low river bed and the higher grounds further away from the river, which are poorer and sandier. The settlement appeared near the arable lands. Further south, in the bush and heath lands sheep were grazed and heath was cut to serve as ground cover for the sheep stalls. This was afterwards used as manure for the arable lands. The farmers growed vegetables, buckwheat, rye, barley and later potatoes, amongst others. They also had some cattle, which grazed on the river banks. It is this, during many centuries used agricultural system that is the first basis of the cultural landscape of Vilsteren. The settlement and more specific the location of the farms in the settlement is also an important part of this landscape. In Dutch this is called the “Esdorpenlandschap”.

The second cultural layer of the landscape is the so called “Landgoederenlandschap” (Estate landscape). To understand this we need to look a little bit closer to the history of the Estate. From at least 1382 up to around 1700 the Lords of Vilsteren were the lieges of the Bishops. The family van Vilsteren were Roman Catholic. Around 1700 this meant less influence and less political possibilities. Therefore they left for Belgium (Laerne near

Gent). They sold their possessions to their steward; Derck Rees. From then on the Estate went to next generations by inheritance. When the owner was a female, the name of the family owning the estate changed by marriage. From Rees it became Grootveld, Helmich and in around 1880 Cremers. These families started to buy more land, embellish the landscape with parks, forests etc.
They also rebuild farms, build a church for the Parish, build a windmill for the farmers, founded a public school and gave permission to build houses for more inhabitants. In short, they directed the development of the landscape and village. Except for the church and the school they stayed owner of the land. The buildings were managed by a sort of leasehold.

The embellishing of the landscape was first done in the French style. The “zeven alleetjes” (a place were 7 straight sightlines come together) is a reminder of that style. In the beginning of the 19th century the French style was replaced by the more romantic English style. Famous still present examples of elements of this style are “de Kurkentrekker” (the corkscrew), “de Theekoepel” (the tea pavilion) and “de Kluizenaarshut” (the hermit’s cabin). These so called follies are part of an around 1810, by landscape architect Georg Blom designed philosophical stroll in the English landscape style.

The present day main building of the Estate (Huis Vilsteren) was built on the same spot were the Van Vilsterens already had their whereabouts. It was built in 1906 by the architect Eduard Cuypers. The landscape architect Dirk ter Steeg designed the garden around the House.

At present the Estate is almost 1.000 hectares large (one of the ten largest in the Netherlands). It is managed as a business with the now 35 descendants of the family Cremers as shareholders. The daily management is done by the director-steward and 6 employees.

Especially the mutual cohesion between the various elements, the relationship with the community, the completeness of the historical landscape, the great cultural values and the sound economic situation, make it to an unique Estate in the Netherlands. The government acknowledged this by adjudging it with several levels of being a national monument.

More information on this estate can be found on: *www.landgoed-vilsteren.nl*

Als Ad het wil

Wilbert Friederichs © 2008

Die Donau so blau, so blau, so blau
maar wat doet-ie nou? Hij stijgt zo gauw…

Is de Rijn wel diep genoeg,
is de Waal nog wel zo veilig?
Stijgt de Donau niet te vroeg,
is het polderlandschap heilig?

Je hoort zo van die vragen her en der
maar gelukkig hebben wij het NCR.
Ach, het loopt met de rivieren heus wel los
want we hebben Ad van Os.

Ay ay Olga, als jij niet van me houdt
dan spring ik in de Wolga en de Wolga die is koud.

Maar de Wolga, al is Rusland ook zo ver,
wordt van hieruit aangestuurd door 't NCR.
En de hele woeste Wolga staat ook stil
als Ad het wil.

Fijn, zo'n reisje langs de Rijn, Rijn, Rijn,
's Avonds in de maneschijn, schijn, schijn.

En is de Rijn soms Lek, dan is normaliter
alvast een oplossing bedacht door 't NCR.
Misschien wel door de slimme Irma Spons?
Of door Ad - want Ad waakt over ons.

Jolien, Jolien, Jolien, Jolien
heb jij die fax van Delft nu al gezien?

Jolien, Jolien, Jolien, Jolien
heb jij Deltares al gemaild, misschien?

Margot, Margot, Margot, Margot
ga jij maar vast wat drinken, ik kom zo.

Overstroming, Ike, Katrina, zout of zoet,
calamiteitenzorg of smelt - het komt wel goed.
Het NCR maakt in de wereld het verschil
als Ad het wil,
als Ad het wil.

Terug naar het water

Misschien valt het wel mee:
we zijn gewend aan water,
aan rivieren en aan zee.
Eerst is het eng maar later
is het wel oké;
als een zakje in de thee.

Wilbert Friederichs

ik blijf hier tot de eeuwigheid
ik trof er zelfs een keer een meisje
maar raakte haar terstond weer kwijt

refrein (aangepast):
Dus spring in de Waal...
spring in de Waal
Oh het is toch enkel smart
toch gaat ze met mijn hart
aan de haal
(parlando:) al breken ze mijn botten
en al vreten ze me kaal
(gezongen) en als ik ben gesprongen
zit er water in mijn longen
dan denk ik tsjonge-jonge wat een rotzooi allemaal
er is maar één.....

het is hier net als overal hoor
toch heb ik nooit zoveel gehad
zeg publiekelijk: ik val voor
die onweerstaanbaar mooie stad.

3.
Er is dus hier wel vaak ellende
waar ik, al wil ik, niks aan doe
want hoe de stad me ook verwende
ze sloeg meedogenloos vaak toe
maar wordt het mij eens zwaar te moede
wel mensen hoor dan mijn moraal
er is een doekje voor het bloeden
dat is gelegen in de Waal.

10 years NCR event

The 10th anniversary of NCR was celebrated with a special event at the end of the first day of the NCR-days.

The entertainment group Flater gave a splashing show in which they sang a series of songs some of them related to rivers or water management in general. One song was specifically dedicated to the programming secretary of NCR, Ad van Os about to be leaving this job after ten years on December 31st, 2008

This was followed by a short speech of Ad looking back on the past 10 years and thanking his two co Founding Fathers, Eelco van Beek and Eric Marteijn.

The day was closed by a buffet diner for all participants and a long stay in the bar afterwards for some of them.

Workshops

Safety in the delta – robust designs

Report of Dutch workshop during NCR days 2008

Summary by C.D. Erdbrink
Deltares, section of River dynamics and inland water transport, christiaan.erdbrink@deltares.nl

Introduction

Our country holds more than fifty ‘dike ring-areas’ (dijkringgebieden), each having a frequency norm on which the construction height of the dike body is based. Research in the past decades has delivered the idea that these norm definitions and design philosophies are ready to be updated. The recent report by the Veerman committee is making a plea for higher national water safety standards, but leaves the question of how we are to attain these standards open.

Meanwhile, the Dutch water boards (‘waterschappen’) are eager to put their shovels into the ground and start maintenance on the retaining earth bodies. How sensible is it for them to build or repair a dike exactly up to the level as prescribed by today’s law? The ever-present risk for the water boards is that they have to take up their shovels two years later to rebuild the same dike. They prefer to apply the so-called ‘robust’ method by building the dikes a great deal higher than strictly necessary, in order to ensure their safety for the next thirty years. This way the uncertainty of future developments that may lead to changing norms is accounted for.

Structure of workshop

Three speakers from various national water-related organisations were invited to give their view on the theme of robustness of hydraulic structures. Each of them held a presentation in twenty minutes. These presentations clearly put forward the different points of view between the fields research, policy and management/ construction.

Research

Annemargreet de Leeuw (Deltares) illustrated the way of thinking of water researchers by concisely treating a few key notions such as the dike-ring approach (‘dijkringbenadering’) and the idea behind the present methodology of performing checks of approval according to Dutch law (‘Wet op de Waterkering’). The Veerman committee has indicated that we move towards a risk-based approach, in which the consequences of a flood also play a role. Further analyses, e.g. of different types of risks, are needed to implement this approach.

Policy

The next speaker, Ilka Tánczos (Waterdienst, RWS) made clear what the focus of policy-makers is in dealing with new insights and plans. Her presentation even provided useful inside information from the policy world for the researcher.
In this light it was emphasized that policy-makers cannot handle theoretical uncertainties. Moreover, they always want to be able to overlook all consequences of possible decisions beforehand. As long as

there is no agreement among scientists on a certain topic, it becomes hard to make definitive, tenable decisions about it. Because policies are often subject to trends and processes that can easily span many years, the timing of raising new research themes can be crucial. Preserving continuity of running policies can be a reason not to adopt (or even ignore) new insights.

Management and construction

Frans van den Berg (Waterschap Rivierenland) talked about the set of tools that are used by his water board to execute the ideas of the policy-makers. The various manuals and guidebooks act as primary source, by some called a 'sacred foundation', of the water board's constructive actions.
To make his work more efficient, Van den Berg pleaded for an extension of the plan period ('planperiode'). According to him, citizens rightfully fail to understand why a local dike has to be rebuilt only a couple of years after the last elevation works.
Several examples clarified some of the practical dilemmas that water boards are faced with in dealing with the management and construction of river dikes. Finally, proof of universal uncertainty appeared by the observation that even approved dikes (that comply with the norms) can collapse.

Discussion

The three speakers formed a panel for the remainder of the workshop. The discussion was led by chairman Kees Vonk (Waterschap Rivierenland), who attacked both panel and audience with sharp and provoking questions. The presentations had uncovered some fierce differences between the three groups which served as good starting points for discussion. A common complaint is that many studies end with recommendations for more research, which does not help the process of making decisions. The workshop attendees, most of whom representing the researcher's viewpoint, had no problems to comment on such issues. Chairman Kees Vonk nevertheless persisted bravely and corrected flaws in some of the arguments. These are a few other questions that constituted the discussion:

- How often should one in all fairness allow the elevation of an existing dike?
- Is current research in line with the demand for research?
- What should be the focus of future river research?

Conclusions

In this workshop it has become clear that the group's policy, management and research each have their own view on delta safety issues in the Netherlands, while at the same time they need to cooperate with each other. The chairman's proposal to conclude that it is beneficial for these groups to more frequently talk to each other aroused mixed reactions from the audience. Some argued that there is more than enough talking already, others agreed that it is useful to keep each other informed.

All in all, the participants largely achieved consensus about the general benefit of doing more river-related research. Although management and policy parties often merely have limited interests in research, it is good to enable mutual adjustments to make it possible to answer specific short-term questions. Beside this, there has to be room for long-term studies, which incidentally can very well be of a practical nature. Examples that were named include questions like which measures are suitable for vulnerable river areas and how much water can flow over a dike before it fails.

Key Note: Living with droughts?

E. van Beek[1,2]
[1] *Deltares, PO Box 177, 2600 MH Delft, the Netherlands, Eelco.vanBeek@Deltares.nl*
[2] *University of Twente, Faculty of Civil Engineering, PO Box 217, 7500 AE Enschede, the Netherlands*

Abstract
The Netherlands Center for River Research (NCR) in its first 10 years of existence has focused its activities on flooding. Climate change might cause that droughts will become as important as or even more important than floods. The dry year 2003 in Europe has shown the huge socio-economic impacts of droughts. New concepts are emerging on how to deal with droughts. This key-note addresses the issues of droughts and scarcity and makes a plea to include more drought research in NCR.

Introduction
Too much, too little and too dirty are presently the main problems that water management has to address. In the Netherlands there has traditionally been a focus on too much, i.e. flooding. This can easily be explained by the fact that 2/3 of the country is subject to flooding threats, either from the rivers or from the sea. Much has been done to reduce the flooding risk in the country. Some flooding risk will remain and one might argue about the need for additional measures. At the same time people start to realize that drought risk might be of a comparable magnitude and measures are needed to reduce this drought risk. The discussion has been triggered by the very dry summer of 2003 (see Figure 1) which affected 100 million people in Europe and 1/3 of its territory. The costs to the European economy of this drought were a staggering € 8.7 billion.

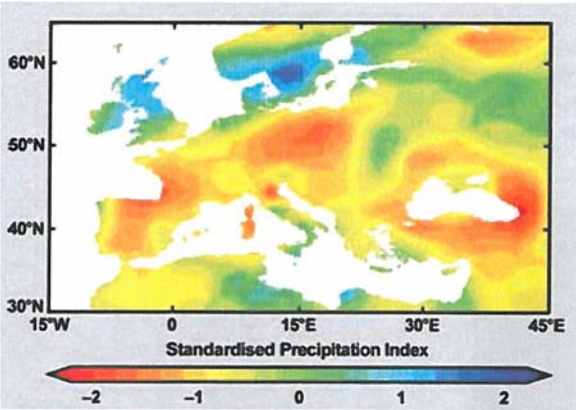


Figure 1. The 2003 drought in Europe

Also the Netherlands suffered from the drought in 2003 but, as Figure 1 shows, less than the rest of Europe. In particular the agricultural and shipping sectors appeared to be vulnerable. Climate change can worsen the situation. KNMI (2006) has developed 4 possible scenarios for climate change in the Netherlands. One of these scenarios (W+) implicates that the dry summer of 2003 will become the average situation. If this will become true major interventions are needed to reduce the damages that the sectors will suffer.

The Deltacommissie (2008) has recognized this and included some of these measures in their advice.

Droughts and scarcity
A clear distinction between droughts and scarcity should be made. A *drought* is a natural climatic phenomenon during which there is a temporary decrease in water availability. *Scarcity* at the other hand is a more permanent situation in which the habitual level of consumption is higher than the average availability. Scarcity is not an issue in the Netherlands given the fact that the average precipitation is 750 mm per year, the evaporation only 500 mm per year and the Rhine and Meuse provide additional inflow. But the country can suffer from drought as the year 2003 has shown. What makes droughts particular in relation to floods is that a drought has a very slow onset and is difficult to predict. When a drought seems to develop and people get worried, it suddenly can start raining again. But if it really continues, it will, compared to flooding, have a long duration and have a large spatial extent. Measures against flood are rather straightforward: strong dikes, give river more room, etc. Measures to mitigate droughts are much more difficult. What can be done if there is no water anymore? Massive storage (surface water and/or groundwater) during wet periods is the most important viable action against droughts but storage projects are very expensive and in most cases not cost-effective.

As mentioned above, scarcity reflects the situation where the demand is higher than the average supply. Scarcity is a relative concept that depends on what people are accustomed to consume in relation to their supply. Absolute water scarcity can be defined to occur if the basic needs for drinking water supply can not be met anymore. However, the net demand of drinking water is often small and in many countries less than 5% of the total demand. In nearly all countries where scarcity is an issue, it appears that this scarcity depends on the level to which a society likes to produce its own food. Take Egypt as an example, a country with hardly any rainfall and a fixed supply of Nile water available to them to serve all its water related needs. Irrigated agriculture is by far the biggest water user in Egypt (> 92%). The growing population continues to ask for more food, food that can only be produced if sufficient irrigation water is available. Already in the present situation this is not the case and Egypt is forced to import food. Such food imports will have to increase in the future to feed the people.
As indication of scarcity in absolute terms often the threshold value of 1000 m^3/capita/yr is used. This includes the water need to grow its own food. Egypt has passed that threshold already in the nineties. As threshold of absolute scarcity sometimes 500 m^3/capita/yr is used. Population predictions for 2050 which will bring Egypt down to 420 m^3/capita/yr.

Changing perspectives
Growing populations and a fixed or even decreasing supply require countries to change their perspectives on how they deal with their water issues. This is illustrated in Figure 2 for the Egyptian case.

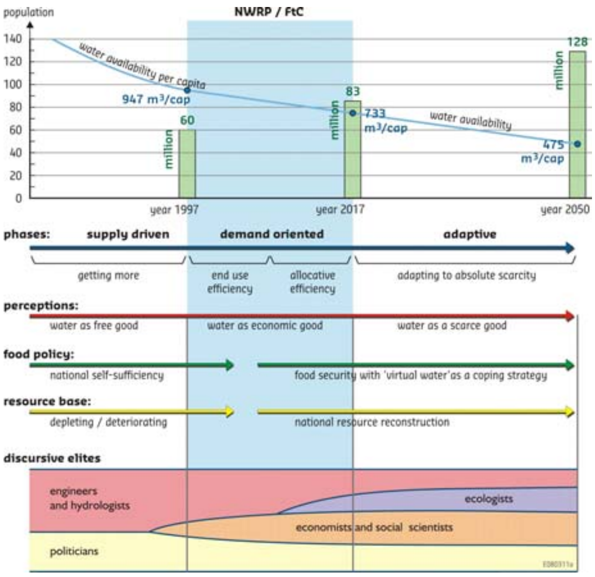


Figure 2. Changing perspectives in water management in Egypt (modified after Turton).

First of all countries will have to change their supply driven approach (just provide more water if this is asked for) to a more demand oriented approach (more efficiency) and next an adaptive approach to cope with the scarcity (e.g. different land use). Related to this is the need to consider water as an economic good and use pricing as an incentive measure to further increase the efficiency of the system. The food policy of the country should drop the usual self-sufficiency approach and change their policy to food security by means of food import. This will also enable the restoration of the often depleted resource base. It is not surprising that this all asks for the inclusion of more economists and socialists in the planning and management of the water resource systems. To support these changing perspectives much research in needed.

Virtual water - water footprint
The solution to scarcity, but in some way also to drought, is to divert water from agricultural use to other sectors where water will have a higher added value. The revenue that this generates can be used to import food. The term 'virtual water' is introduced to illustrate how much water is involved in such shifts. Virtual water is the water needed to produce a product and which is virtually embodied in that product. Figure 3 gives the virtual water content of some products.

Figure 3. Virtual water content of a few products.

The 'water footprint' of a product is the volume of fresh water that is used to produce the product, summed over the various steps of the production chain and includes the temporal and spatial dimension when and where the water was used. The 'water footprint' of a nation is the total amount of water that is used to produce the goods and services consumed by the inhabitants of the nation and is equal to the national use plus the virtual water export minus the virtual water import.

These concepts show that consumers indirectly can contribute to water depletion in other countries, in most cases without covering the cost. By recognizing that water-abundant regions have other opportunities than water-scarce regions, huge regional water savings can be made. Such shifts will make that nations become increasingly dependent on external water resources. By this water is becoming a geopolitical resource and with that a globalisation of water will take place. This all makes that there is a growing need to harmonize national water and trade policies.

Conclusion

Drought and scarcity situations are expected to increase in occurrence and impact due to climate change and population growth. The socio-economic impacts of these events are enormous. Still, compared to floods, the amount of research in the Netherlands in this field is limited. Research opportunities for NCR are in the physical (e.g. hydrology), economics as well as social fields.

References

Loucks, D.P. and E. van Beek (2005), Water Resources Systems Planning and Management, an introduction to Methods, Models and Applications, UNESCO

Hoekstra, A.Y. and A.K. Chapagain (2008). Globalisation of water: sharing the planet's freshwater resources, Blackwell Publishing

KNMI (2006). Climate in the 21st Century, four scenarios for the Netherlands, KNMI

Deltacommissie (2008). Samen werken met water. Een land dat leeft, bouwt aan zijn toekomst (in Dutch); see also pages 8-12 of these proceedings

Turton, A. R. (1999). Water scarcity and social adaptive capacity: towards an understanding of the social dynamics of water demand management in developing countries. Occasional Paper, No. 9, University of London, UK

Dealing with Droughts

Report of workshop during NCR days 2008

Summary by E. van Beek[1,2]
[1] *Deltares, PO Box 177, 2600 MH Delft, the Netherlands, Eelco.vanBeek@Deltares.nl*
[2] *University of Twente, Faculty of Civil Engineering, PO Box 217, 7500 AE Enschede, the Netherlands*

Introduction and objective

As mentioned in the key-note drought issues are expected to increase in importance as a result of climate change. Droughts are often associated with desert like conditions in Africa but also in Europe droughts occur. Given the socio-economic values involved and the fact that measures to prevent droughts are very costly, droughts may in future even get a higher political weight than flooding, also in Europe. This will certainly be the case in countries where droughts are now already important socio-economic issues such as in Spain and Italy.

Some NCR partners are already involved in drought related research but much less than in flooding research. The question arises if NCR should pay more attention to droughts and if so, how and who should be involved. These questions were discussed in this workshop. The workshop started with two introductory presentations, one about the Netherlands by dr. H. Berger and one about developing countries by prof.dr. H.H.G. Savenije. Based on these presentations a plenary discussion was held. The workshop was attended by 26 participants.

Droughts in the Netherlands

Dr. H. Berger
(RWS, Centre for Water Management)

The Netherlands has in general sufficient water. The precipitation deficit in summer is at average about 100 mm and most of this deficit is available for the plants from soil moisture. Moreover, the Rhine River supplies huge quantities of water to the country, also during dry years. However, most of this Rhine discharge is needed to push back the salt intrusion in the Rotterdam Waterway and for flushing of the polder-boezem systems. On top of that not all of the Netherlands can be supplied with this Rhine water; in particular the higher areas in the East and the South of the country lack the necessary infrastructure. This means that during dry years such as 2003 and 1976 droughts do occur also in the Netherlands. Some of the new KNMI climate scenarios predict that these shortages might occur more often in future. In the so-called W+-scenario the dry year 2003 will become the average situation. Both the farming and shipping sectors have expressed that these sectors will have to take major adaptation

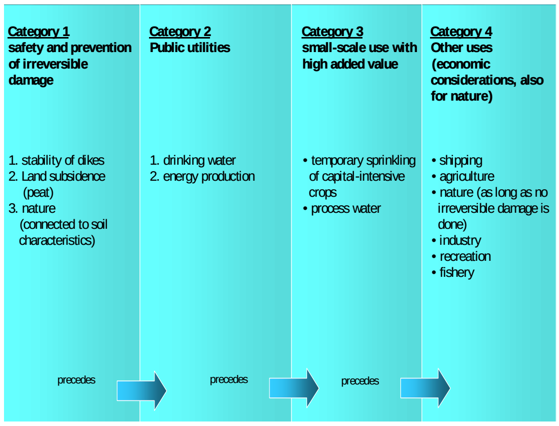


Figure 1. Priority list droughts in the Netherlands

measures, if this scenario would indeed become true.

During periods of drought a National Coordination Committee on Water Distribution (Landelijk Committee Waterverdeling - LCW) advises the responsible authorities on operational measures to be taken. These measures follow a priority list of water allocation as presented in Figure 1.
This priority list aims to reduce the overall damage to the country.
The Dutch government is of the opinion that droughts are likely to become more important and for that reason has initiated an applied research project to make the water supply in the Dutch climate change proof. The main purpose of that project is to develop a feasible water policy in which supply and demands are again in balance, also during dry periods. Research questions have been derived that need to be answered. NCR is invited to address these questions.

Discussion between two of the key figures of the Droughts workshop

Dealing with droughts in developing countries

Prof. H.H.G. Savenije (TUD)

Droughts in Africa are the classical examples of what can go wrong during dry periods if insufficient measures are (can be) taken. Many African climate zones show clear meteorological and river discharge variabilities, both within years and over years as illustrated in Figure 2 for the Zambezi. These changes in time are significant and subject to a lot of research. What gets much less attention is that as a result of land pressure people are migrating into other climatic zones and other landscapes. This means that we have to deal with change of quantity in time and space expressed as follows:

$$\mathrm{d}Q = \frac{\partial Q}{\partial t}\mathrm{d}t + \frac{\partial Q}{\partial x}\mathrm{d}x$$

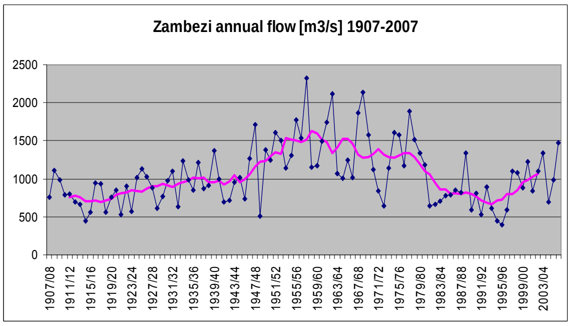


Figure 2. Zambezi long-year flow patterns

The main message of the presentation was that as a result of increasing land pressure land use will change, the discharge regimes will change (sharper flood peaks, less low flow), upstream withdrawals will change and there will be changes in partitioning, storage and function. It is argued that all these changes are more important than climate change.

Some coping strategies were presented that are applied in such systems. These typically rely on so-called “Smallholder System Innovations” which include rainwater harvesting techniques, minimum tillage and an irrigation technique that is locally known as “Fanya Yuu’s”. The approach in Africa is clearly different from what is applied in Europe but lessons can be learned and research need to be carried out to develop these systems further.

Workshop discussion

Chaired by E.C.L. Marteijn (RWS)

The main questions to be answered in the workshop were:

1. Do we consider drought an important research topic for NCR? and if so

What actions should NCR take to stimulate this?

The discussion started with an inventory with all kind of aspects that should be addressed in drought research. Participants indicated a strong need to know more about the economic aspects involved and about the vulnerability of the system. So far damages included are only the direct costs, e.g. for the shipping sector. It was recognized that the indirect costs might be much bigger, e.g. for the industry if insufficient supplies can be delivered because of the transportation problems.

With respect to agriculture in the Netherlands it was concluded that compared to Europe the Netherlands is less vulnerable to drought because of the high groundwater table and the abundant water supply. Increased prices at the European market will outweigh the less production and as such drought could be good for the Dutch economy as a whole. This means that besides looking for solutions to avoid damages, we should also look for opportunities, i.e. develop tailor made solutions. It means also that a clear distinction should be made between a financial (cash-flow) and an economic analysis. Opportunities could include the use of Remote Sensing techniques for operational uses. WaterWatch has already carried out pioneering research in this subject.

In general it was concluded that compared to flooding we know very little about the physics and economics of droughts. Lessons could be learned from the recent 2003 drought and the somewhat older but even more severe 1976 drought. At the other hand we should not only look at individual years but look at longer time series. This ultimately could lead to the development of a ‘drought risk approach’ comparable to the flood risk approach that received a lot of attention in NCR. Several links with other subjects were mentioned, in particular energy and water quality. Water quality is in particular addressed in the Water Framework Directive (WFD) and the basin approach of the WFD is also needed to deal with droughts.

Conclusions and recommendations for NCR

The general conclusion of the workshop was that drought is indeed a promising research topic for NCR and that NCR should develop activities to stimulate such research among their members. That research includes physical topics (understanding the issue), the economics involved and possible adaptation measures. To include climate change it will be needed to increase the cooperation with KNMI.

For the economic aspects it will be needed to invite more economic oriented research institutes such as IVM of the Free University (VU) to join in the research. Cooperation with PBL (Planbureau voor de Leefomgeving) is needed to derive consistent economic and spatial planning scenarios. NCR is challenged to pick this up, using their extensive experience with similar research on flood risks.

Impression of the lively discussion during the various breaks

A numerical-constraint based approach for flood mitigation in low lying areas

M. Zagonjolli, A.E. Mynett
Deltares, P.O. Box 177, 2600 MH Delft, the Netherlands; migena.zagonjolli@deltares.nl

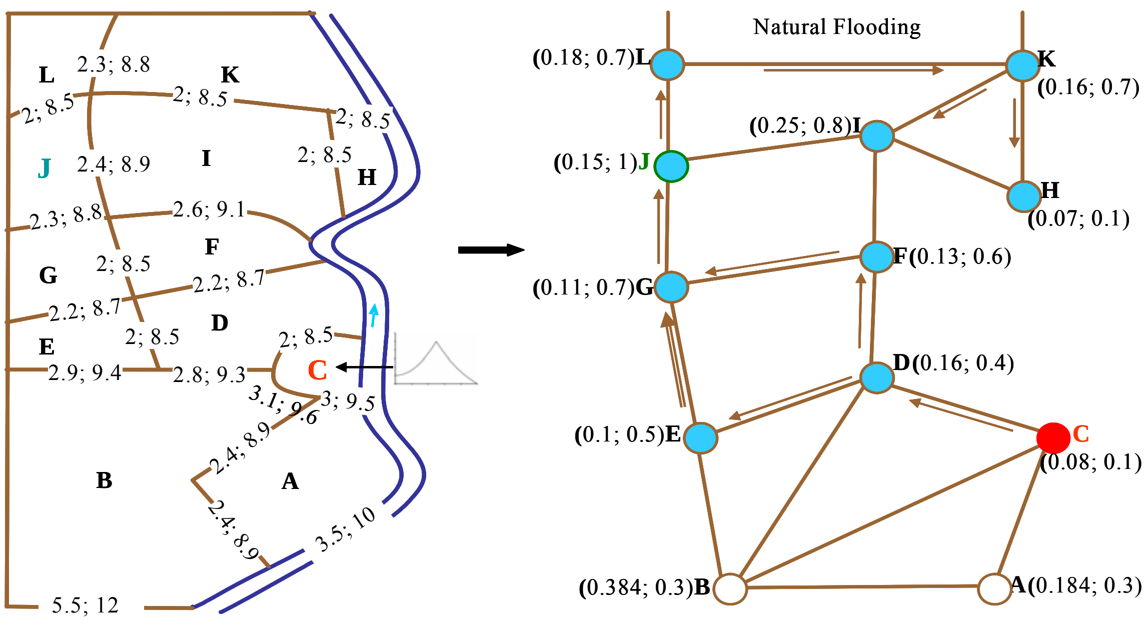
Introduction

During past decades different methodologies were proposed to prevent and manage floods. In this paper, instead of focusing on methodologies to minimise the probability of a flood event, we consider an alternative approach that aims at decreasing its consequences. Simulation of the consequences of a predicted or assumed flood is typically elaborated in what-if scenarios. Every what-if scenario requires specification of the initial state and the configuration of the system. Considering different scenarios makes the number of required simulations grow increasingly large. Therefore, in practice, only a small fraction of all possible strategies can be explored.

A numerical–constraint based model (Zagonjolli et al., 2006) is developed for evaluating risk and mitigating consequences in a system of polders or low–lying areas. The model is capable of simultaneously evaluating different flood mitigation scenarios in a very short time by utilizing algorithms based on 'graph theory'. The results of a case study which takes into account different objective functions such as storage capacities and economical values of a multiply connected polder system, look quite promising for flood risk mitigation.

Description of the numerical-constraint based approach

The key elements of the developed numerical-constraint based technique are the *graph algorithms* (Corman et al., 2001). Figure 1 shows the transformation of a flood prone area into a graph. The area surrounded by outer dikes (boundary dikes) consists of 12 polders separated by inner dikes (dikes that belong to more than one polder). Each of the polders, represented as a vertex of the graph, has a maximum capacity to store flood water. For each inner dike there is an edge connecting two vertices (polders). Therefore, all possible ways of flood propagation in the area prone to flooding are represented as *all possible paths from the initially flooded polder to the polder that needs to be protected* referred hereafter to as *protected polder*. For example, we can assume an initial breaching to occur at the river dike in polder **C** as a result of hydraulic conditions or as a result of the decision to deliberately initiate breaching at that particular location. We also assume that polder **J** is estimated (based on the given evaluation) to be the most important polder that requires maximum protection.



a) **b)**

Figure 1. Transformation of the area into a graph. Dike height and dike top elevation (in a) as well as polder area (km^2) and its relevant value (in b) are presented.

The main questions arising while addressing a flood mitigation problem, that is *find all possible paths for flood water before it arrives at the protected area*, is efficiently addressed by the proposed numerical-constraint based model. Objects having national significance can be taken as an important constraint for inundation of a particular area, and - together with the population at risk - will contribute to the overall score of the polder's value.

Within the framework of the proposed approach the interactions between compartments of a dike ring are taken into account. To minimize flooding impact on the complex hydraulic system of dike ring areas, different objectives could be taken into consideration during the simulation process:

1. Natural flooding: flooding of the compartments naturally occurring under specific hydraulic conditions.
2. Maximum Storing Volume: selection of polders to be flooded based on their maximum volume capacity.
3. Minimum Total Damage: selection of polders to accommodate the flood water based on their socio-economic, cultural and environmental value. Less valuable polders to be flooded first.

Application

A socio-economically feasible flood propagation scenario could be imposed by enforcing a minimal total damage constraint. The key idea behind this approach is to identify and deliberately flood areas that have the least economic value. Thus, controlled flooding is aimed to produce the least total damage although deliberately flooded areas might have low flooding probability. The graph algorithm finds a path along the least valuable areas in the domain based on the user defined input data in terms of socio-economic, cultural and environmental value.

In Figure 1b the natural propagation of the flood in the domain is shown. It can be observed that Polder **J** is flooded. The arrows present the flow direction and the blue colour identifies the inundated polders. Different flood path propagation is obtained for the minimum total damage scenario (see Figure 2).
The Polder **J** is dry at the end of this simulation with the flow mitigated towards the less valuable polders A and B.

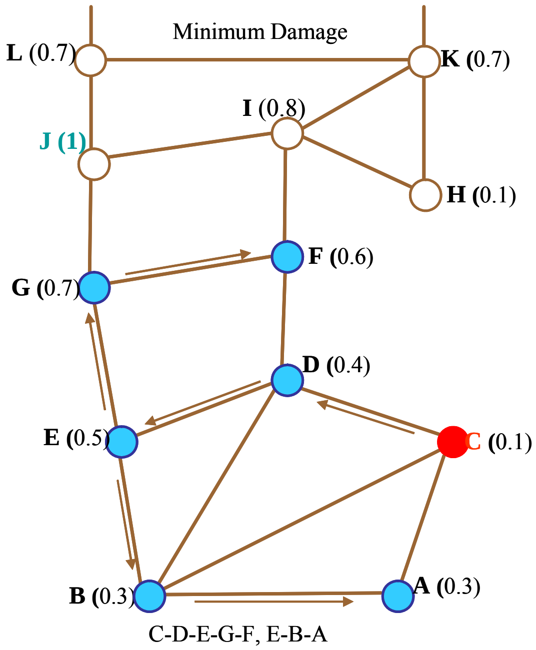


Figure2. The flooding of the polders based on the minimum value objective.

Conclusion

The approach developed in this thesis can be used to complement existing practices of flood modelling, which are traditionally carried out by simulating the consequences of a forecasted or assumed flood event and elaborated into a few typical 'what - if' scenarios. The 'lightweight' numerical–constraint based technique proposed in this thesis is capable of evaluating many scenarios in a very short period of time by first determining the most feasible scenarios, which can then be modelled in more detail using a conventional hydrodynamic simulation approach. In this way computation time is considerably reduced while focusing on the most feasible options is ensured.

Clearly a combination of these two methods can either be achieved by enhancing a hydrodynamic modelling package with an optional numerical–constraint based approach, or vice versa.

References

Corman, T. H., Leiserson, C. E. and Rivest, R. L.: 2001, Introduction to algorithms, MIT Press, Cambridge, USA.
Zagonjolli, M., Goossens, H. and Mynett, A. E.: 2006, A numerical-constraint based approach for flood mitigation in dike ring areas, Proc. of 7th International Conference on Hydroinformatics, Nice, FRANCE.

Climate change and adaptive capacity to extreme events in the Rhine basin

A.H. te Linde[1,2], J.C.J.H. Aerts[1]
[1]*Institute for Environmental Studies (IVM - VU), De Boelelaan 1087, 1081 HV Amsterdam;* aline.te.linde@ivm.vu.nl
[2]*Deltares, Rotterdamseweg 185, 2629 HD Delft.*

Abstract
Impacts of land use change, flood defence measures and climate change on peak discharges are studied at different scales in the Rhine basin. Few studies, though, have studied the combined effect of these variables in scenarios and how these scenarios change the return period of flood peaks. In the current paper we introduce a method to combine simulations of the effect of upstream flooding and climate change on flood-peak probability.

Introduction
Recent floods and droughts reinforced cross-boundary cooperation on flood management in the Rhine basin (e.g. IKSR Flood Action Plan, Dutch-German Working Group on Floods (since 1997), EU Floods Directive (2007)). However, these initiatives do not consider the effect of climate change in the Rhine basin, while recent research findings conclude that as a result of climate change peak discharge is likely to move from spring to winter due to early snowmelt in addition to precipitation increase (e.g. Kwadijk and Middelkoop, 1994; Middelkoop et al., 2001; Kleinn et al, 2005). Furthermore, historical time series are too short to derive a statistically sound extrapolation of return periods of flood peaks with a low probability. In the current paper we introduce a method to simulate low probability floods, and combine the effect of upstream flooding and different climate change scenarios on peak discharges.

Method
All modelling steps are visualized in Fig. 1. We used the semi-distributed conceptual HBV model for rainfall modelling and the hydrodynamic model SOBEK to recalculate all yearly maximum discharges. To produce discharge series of at least 1000 years we applied the stochastic rainfall generator developed for the whole Rhine basin by Beersma (2001).
We constructed specific climate scenarios for the Rhine basin by applying the delta change approach on a historical dataset (1961-1995), based on the KNMI'06 scenarios (Te Linde, 2007). But the delta change does not take into account possible geographical differences in future change of precipitation and temperature. Also, the present day variance of those parameters is left unchanged, while changes can be expected due to climate change. To overcome these limitations, we applied a method that uses (bias-corrected) direct output from the regional climate model (RCM) RACMO (Lenderink, 2003), forced by GCM ECHAM 5 as well.
To estimate extreme discharges at Lobith, we added an extra shape parameter to the Gumbel distribution, and applied the Weibull distribution.

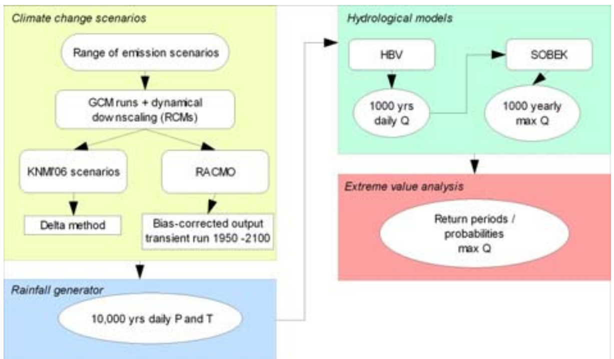


Figure 1. Flow chart displaying all modelling steps

Results
Climate change impact
Following the climate change scenarios, mean winter discharge is expected to increase by 11 % according to the Wp scenario and to 14 % according to the RACMO scenario (Table 1).

Table 1: Seasonal change in discharge at Lobith according to KNMI'06 scenarios and RACMO output, for 2050

Q (m3/s)	DJF	MAM	JJA	SON	Year
Observed 1961-1995	2778	2518	2314	1809	2355
dQ G (%)	6.71	2.03	-2.16	1.47	2.01
dQ Gp (%)	5.58	3.00	-17.40	-17.36	-6.61
dQ W (%)	13.04	4.47	-3.94	3.02	4.15
dQ Wp (%)	10.56	6.50	-31.68	-33.25	-11.97
dQ RACMO (%)	14.20	-0.75	-17.36	-12.63	-4.14

Figure 2 shows that the spatial variation of the projected change differs to a large extent between RACMO and Wp. This is most likely a direct result from the spatial variation in direct RCM output, compared to the uniformly spread delta change approach.

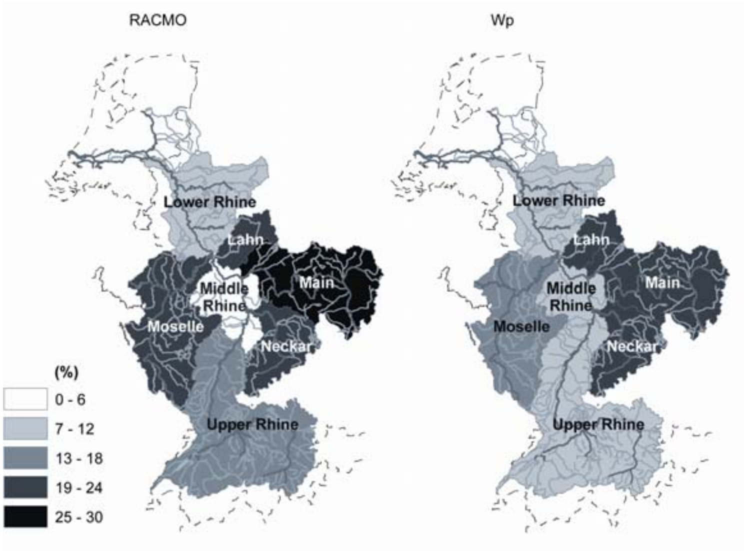


Figure 2. Mean change in winter discharge for the Wp and RACMO scenarios (2050)

Interpreting extremes and effect of flooding

According to Figure 3 and Table 2, the flood frequency will increase as a result of climate change. For the situation without flooding, a peak discharge of 15,000 m^3/s with a return period of 500 years (Gumbel variate is 6.2) in the reference situation will shift to a return period of 100 years (Gumbel variate is 4.6) in the Wp scenario. Also, the 1/1000 year event of 15.700 m^3/s in the reference situation will shift to 18.200 m^3/s in 2050. If we do take into account the simulated effect of flooding, these differences in peak discharges and return periods between the reference and the Wp scenario for 2050 are less dramatic. The 1/1000 year event will then shift from 14.000 m^3/s in the reference situation to 15.000 m^3/s in 2050, which is a reduction of 10 – 15%.

Table 2. Estimated return periods obtained by ranking the peak events at Lobith according to size and linking return periods to the ranks. A dataset of 1000 years was used

Return period	Reference		Climate change (Wp)	
	Without flooding	With flooding	Without flooding	With flooding
1000	15,700	14,000	18,200	15,400
500	15,000	13,700	17,700	14,800
200	14,300	13,100	16,700	14,500
100	12,900	12,600	15,200	13,600

Conclusion

Results show that the flood-peak probabilities are likely to increase as a result of climate change in the Rhine basin, and that there are large (spatial) differences between climate change scenarios. The simulated effect of flooding decreases peak discharge at Lobith by 10 – 15%. We used a modelling method that combines a weather generator and different climate change scenarios with hydrological modelling.

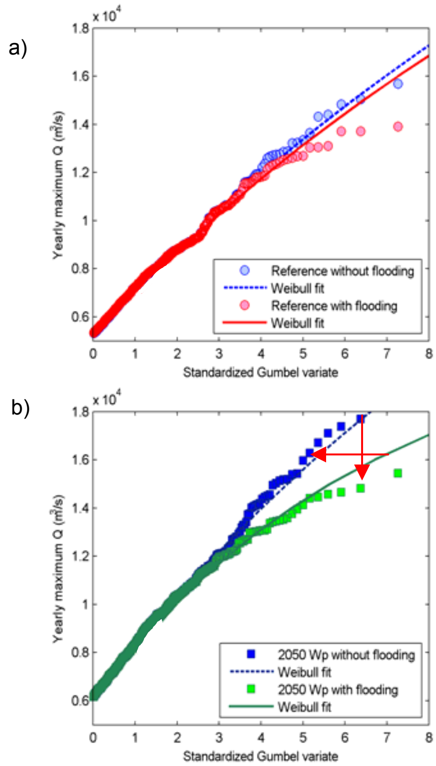


Figure 3. Extreme value distribution of yearly maximum at Lobith The Weibull distribution fits are shown without confidence intervals. Displayed are the reference situation (a) and 2050 ac-cording to the Wp scenario (b)

This enabled us to simulate low probability floods, and to combine the analysis on the effect of upstream flooding and different climate change scenarios on peak discharges.

References

Beersma, J.J., Buishand, T.A., Wójcik, R. (2001) Rainfall generator for the Rhine basin; multi-site simulation of daily weather variables by nearest-neighbour resampling. P. Krahe, Herpertz, D. Lelystad, the Netherlands, International Com-mission for the Hydrology of the Rhine basin CHR. CHR-Report no. I-20: 69-77.

Kleinn, J., Frei, C., Gurtz, J., Lüthi, D., Vidale, P., Chär, C. (2005) Hydrologic simulations in the Rhine basin driven by a regional climate model. Journal of Geophysical Research, 110 (D04102, doi:10.1029/2004JD005143).

Kwadijk, J., & Middelkoop, H. (1994) Estimation of impact of climate change on the peak discharge probability of the river Rhine. Climatic Change, 27, 199-224.

Lenderink, G., Hurk, B. Van den, Van Meijgaard, E., Van Ulden, A., & Cuijpers, J. (2003) Simulation of present-day climate in RACMO2: first results and model developments. (Tech. Rep. No. 252). KNMI.

Te Linde, A.H. (2007) Effect of climate change on the discharge of the rivers Rhine and Meuse. Applying the KNMI 2006 scenarios using the HBV model. Delft, the Netherlands, WL | Delft Hydraulics: 1-30.

Middelkoop, H., Daamen, K., Gellens, D., Grabs, W., Kwadijk, J.C.J., Lang, H., Parmet, B.W.A.H., Schädler, B., Schulla, J., Wilke, K. 2001. Impact of climate change on hydrological regimes and water resources management in the Rhine basin. Climatic Change 49: 105-128.

Urban Flood Protection (UFP) Matrix

B. Stalenberg
TU Delft, P.O. box 5048, 2600 GA Delft, the Netherlands, b.stalenberg@tudelft.nl

Abstract
The river landscape has always been appealing for human activities and settlements; creating a network for transport and producing fertile soil for agriculture. At the same time, rivers also threaten the surrounding areas with floods. Protection of assets against these floods has been a battle ever since the first settlements on the river dunes. Nowadays, a challenging task lies in protecting river cities against floods while maintaining or enhancing the urban quality of the water front. That is why a decision tool has been developed which can contribute in realising a synergic riverfront from both, urban planners' and flood controllers', point of view. The Urban Flood Protection (UFP) Matrix consists of a dataset of urban riverfronts and a dataset of flood retaining structures. Additionally, the matrices give an overview of which combinations between the two datasets are possible and which are less likely to become a success. With the UFP Matrix, a synergic combination of flood protection and urban functions can be achieved.

Introduction
Already in ancient times, many people were drawn towards rivers. At first, this was mainly due to its transport possibilities and its fertile soil which was perfect for agriculture. Nowadays, riverfronts are especially attractive for luxurious dwellings and recreational activities. Refurbishment of former harbour areas into attractive living and leisure districts can be seen throughout the world. In these urban waterfronts, sufficient protection against floods is essential. However, simultaneous improvement of the flood defence and the refurbishment of the riverfront are hard to achieve. Main bottleneck of the improvement of flood retaining structures in cities is the possible resistance from local residents. Horizontal expansion of the flood defence often leads to taking down buildings. Furthermore, vertical expansion of the flood defence decreases most likely the value of the area; contact with the river is often lost. Hence, a tension is present between flood protection and urban activities. Nowadays, a challenging task lies in protecting river cities against floods while maintaining or enhancing the urban quality of the water front; especially with the likely increase of river discharges due to climate change.

Objective
The question that arises is how flood protection and urban functions can be synergic combined in the shared realm of an urban riverfront. The objective of this paper is therefore to develop a decision tool that contributes in realising a synergic riverfront from both, urban planners' and flood controllers', point of views.

Development of the UFPM decision tool
For the development of the UFPM decision tool, two methods are used. Firstly, a list of requirements from urban planners and flood controllers shows the wishes and demands of those different stakeholders. A synergic riverfront can only be established if most of the different stakeholders' requirements are met. The UFPM decision tool is developed within this framework. Secondly, several existing reference decision tools, applicable in the field of flood protection, give inspiration for the development of the UFPM decision tool. An example is the decision tool (Pols, Kronberger et al. 2007) that is developed by Ruimtelijk Planbureau (Spatial planning agency). It aims at a reduction of the risk of flooding through the use of spatial adjustments, through better use of the administrative instruments and through changing the public opinion. In general, the reference decision tools show what kind of information can be given in a decision tool and to what extend this information could be elaborated. Furthermore, they show possible interface designs. Combining both methods gives the Urban Flood Protection Matrix.

Urban Flood Protection Matrix
Firstly, the Urban Flood Protection (UFP) Matrix contains two datasets that are combined: a dataset of urban riverfronts and a dataset of flood retaining structures. Secondly, the UFP Matrix contains three matrixes that give an overview of which combinations between the two datasets are possible and which are less likely to become a success. The target groups of the UFP Matrix are urban planners and flood controllers, which can use the UFP Matrix especially during the primary design cycle.

Urban riverfronts

The first dataset consists of eleven types of urban riverfronts. For each riverfront the characteristics and functions are discussed and each riverfront is illustrated with a few photographs. Urban planners can use this overview as inspiration for their first rough sketches while designing an urban riverfront. Flood controllers can obtain knowledge about the different types of urban riverfronts.

Figure 1. Skyscraper front

Flood retaining structures

The second dataset consists of fourteen types of flood retaining structures (Stalenberg and Vrijling 2008). For each structure the specifications are given and each structure is illustrated with a few photographs. Furthermore, the overall stability and failure mechanisms are discussed. Flood controllers can use this overview as inspiration for their first rough sketches while developing a flood defence system for a river city. Urban planners can obtain knowledge about the different types of flood retaining structures.

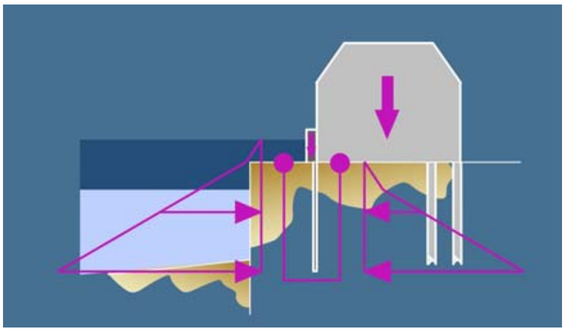


Figure 2. Floodproof houses with overall stability and piping length

The matrixes

The decision tool contains three matrixes which show the feasibility of the design of a combined urban riverfront, form both an urban point of view and a technical point of view. The three matrixes are developed according to the height difference between the flood retaining structure and the ground level behind it. Matrix A can be used for a negligible height difference, Matrix B for height differences less than one meter and Matrix C for height differences more than one meter. Each matrix can be of help by getting insight in the current situation at a riverfront, getting insight if a change in an existing riverfront from an urban point of view or technical point of view is feasible or getting insight in the feasibility of a design of a new urban riverfront. By clicking on a score in a matrix, the score of the combination is explained.

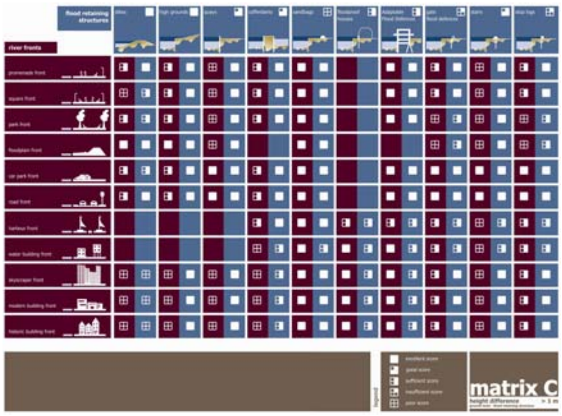


Figure 3. Matrix C for height difference larger than 1 meter

Conclusions

The objective of this paper was to develop a decision tool that contributes in realising a synergic riverfront from both, urban planners' and flood controllers', point of views. This has been realised through the development of the Urban Flood Protection Matrix, meeting as much requirements as possible. The UFP Matrix can be of help with the design of a new riverfront, or an alteration of the existing riverfront, by a team of urban planners and flood controllers, especially during the primary design stage. The UFP Matrix gives inspiration in the design process, it gives insight in each others' fields and it achieves mutual understanding. Hence, it contributes to the process of decreasing the difficulties in improving the flood protection structures and the refurbishment of the urban waterfront in the shared realm. A synergic combination of flood protection and urban functions can be achieved.

References

Pols, L., P. Kronberger, et al. (2007). Flood risk as spatial task (in Dutch). Rotterdam, NAi and Ruimtelijk Planbureau.

Stalenberg, B. and J. K. Vrijling (2008). Overview of flood retaining structures in the Netherlands. Fourth International Symposium on Flood Defence. Toronto, Canada.

Effect analysis of transient scenarios for successful water management strategies

M. Haasnoot[1,2,4*], H. Middelkoop[1], W. van Deursen[3], E. van Beek[2,4], J. Beersma[5]
[1] *Utrecht University, Department of Physical Geography, PO Box 80.115, 3508 TC Utrecht, the Netherlands*
[2] *Deltares, PO Box 177, 2600 MH Delft, the Netherlands,*
[3] *Carthago Consultancy, Oostzeedijk Beneden 23a, 3062 VK Rotterdam, the Netherlands*
[4] *University of Twente, Faculty of civil engineering, PO Box 217, 7500 AE Enschede, the Netherlands*
[5] *KNMI, PO Box 201, 3730 AE De Bilt, the Netherlands*
[*] *Corresponding author: Marjolijn Haasnoot, marjolijn.haasnoot@deltares.nl*

Abstract
Recent scenario studies on water management focus on one or two projection years and the effects on the water system and functions. The future is however more complex and dynamic. Therefore, we analyse transient scenarios in order to evaluate the performance of water management strategies. Current available simulation tools are not suitable for this purpose. Therefore, we have developed and used a tool to simulate 50-100 year long time series and that is good and fast enough to simulate the effects of these scenarios and strategies on the water system and the interaction with the human system. We present the first step by means of a case study.

Introduction
Successful water management involves defining strategies that are not very sensitive to unanticipated changes in pressures (i.e. robust) and do not a-priori exclude alternative strategies (i.e. flexible). Recent scenario studies on water management in the Netherlands were mainly 'What-if' assessments, based on comparing the state of socio-economic and ecological functions of the water systems in one or two future situations with the current situation. The future is however more complex and dynamic. For the identification of robust and flexible strategies we explore a range of possible futures with transient scenarios, thereby considering the interaction between pressures, impacts and management responses in a dynamic way (Figure 1).
Transient scenarios are integrated scenarios which describe time series that include trends, unexpected events, floods and droughts and the interaction between water system and society.

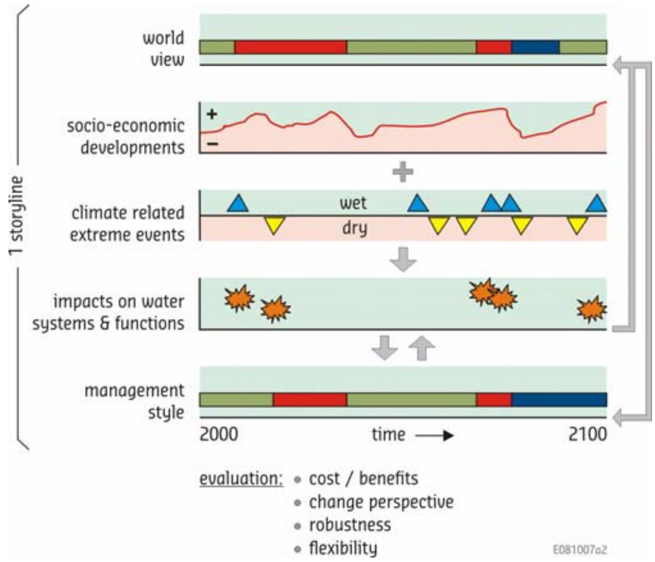


Figure 1. Flow diagram for the effect analysis of transient scenarios.

Objective
The objective of this study is to develop a method to identify robust and flexible adaptation strategies in river deltas under uncertainty, by exploring integrated transient scenarios for the physical, socio-economic and social system.

This study is part of the project Perspectives in Integrated Water Resources Management (Haasnoot et al. 2008).

Method
Most of current available simulation tools require a very long calculation time in case of long time-series or they are unable to run time-series, or they do not consider the society-water interaction involved. Therefore, we developed a Rapid Assessment Model (RAM) that is able to run many long time series and that is adequate to simulate the effects of these scenarios and strategies on the water system as well as the interaction with the human system. This allows for determining transition pathways towards new water management strategies.
The core of this RAM comprises a rule-base of cause-effect relations, describing the physical system, and response curves, describing the world view dynamics and (changes in)

management style. The knowledge rules will be based on a vulnerability analysis, results of detailed hydrological and impact models, and understanding of the dynamics in water management perspectives. The latter will be derived from different methods including desk research and participatory stakeholder workshops (Offermans et al. 2007).

Results

To elaborate the method we first applied to an imaginary case inspired by the river Waal. The transient climate scenarios are based on simulations with the KNMI Rainfall Generator coupled to a hydrological model for the Rhine (Te Linde, 2007) in which the KNMI'06 climate scenarios are incorporated as a linear change up to 2100 (Figure 2). However, the events experienced by society are stochastic in nature.

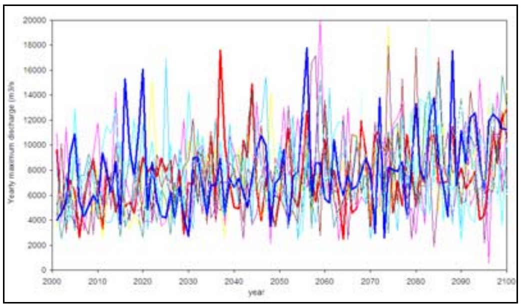


Figure 2. Example of 10 transient scenarios which are all possible realisations of the future. They indicate the maximum yearly discharge of the Rhine at Lobith, based on modelling results under a changing climate (W+ KNMI'06 scenario).

The current version of the RAM is able to analyse the performance of a strategy for a transient climate scenarios and includes the following physical cause-effect relations:

- discharge and water levels along the river,
- water level and probability of dyke failure (based on Van Velzen in prep.),
- water level and shipping costs,
- water level and flooding,
- flooding and damage to houses and agriculture (De Bruijn, 2008),
- flooding and vegetation types (based on Haasnoot and Van der Molen, 2003).

By using transient scenarios, we will be able to evaluate the management response to the occurrence of (extreme) events. For example, a scenario with an extreme flood event around 2040 will have a different impact and response than a scenario with two flood events in 2015 and 2020 (red and blue line in Figure 2). The results of the analysis of transient scenarios will be used to evaluate the management strategies and develop possible adaptation paths.

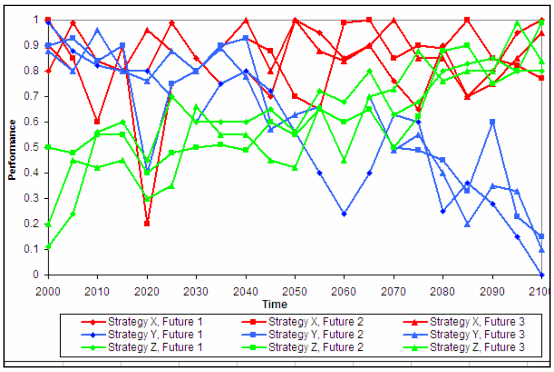


Figure 3. Example of the result of the Rapid Assessment Model. The lines indicate the relative performance of a strategy for different transient scenarios.

An example of a result of the RAM is given in Figure 3. The figure presents the performance of three strategies for three different futures. The performance indicates to what extent the objectives are achieved through time. This gives information on the robustness of a strategy and adaptation paths. 'Strategy X' has mostly a good performance considering all possible futures. 'Strategy Y' decreases in performance and it might be worthwhile to change to 'strategy Z' after 2050. If the objectives change the performance changes as well.

Conclusion

The first results of the study are encouraging to elaborate it further in the imaginary case and test the method in different real cases. We plan to extend the number of possible futures with socio-economic scenarios. Furthermore, we will include perspective based evaluation of the performance of a strategy and include the response of society in terms of world view and management style.

References

De Bruijn, K.M. (2008) "Bepalen van schade ten gevolge van overstromingen. Voor verschillende scenarios en bij verschillende beleidsopties." Deltares report Q4345.00. Delft, the Netherlands (In Dutch).

Haasnoot, M. & D.T. van der Molen. (2003) Impact of climate change on ecotopes of the rivers Rhine and Meuse. In: Lowland river rehabilitation.

Haasnoot, M. et al. (2008) Research proposal perspectives in integrated water resource management in river deltas. Vulnerability, robust management strategies and adaptation paths under global change. Deltares.

Offermans, A. (2007) Perspectives in Integrated Water Management. NCR proceedings 2007.

Van Velzen, E. (in prep.) Overstromingskansen in WV21 (in Dutch).

Discussion support system for long-term flood risk management in the Netherlands

M.J.P. Mens
Deltares, P.O.Box 177, 2600 MH Delft; marjolein.mens@deltares.nl

Introduction

Making decisions about long-term planning for flood risk management is recognized as a complex activity, because of uncertain developments in climate, economy and demography and the many actors are usually involved in making strategic choices. A discussion support system (DSS) could enhance the communication between these actors, by ensuring a common understanding of the problem and by structuring the large amount of information.

Two prototype DSSs have been developed and tested among potential end-users. The DSSs show the long-term effect on flood risk of the current flood risk management strategy, under different future scenarios as well as the effect of alternative strategies. The system allows different users to develop their preferred strategy as a combination of measures. The effect on the future flood risk is directly shown. In addition, costs and indirect effects such as on nature can be evaluated. The additional value of a DSS is that the user learns about the concept of flood risk by playing with combinations of for example dike raising and spatial planning.

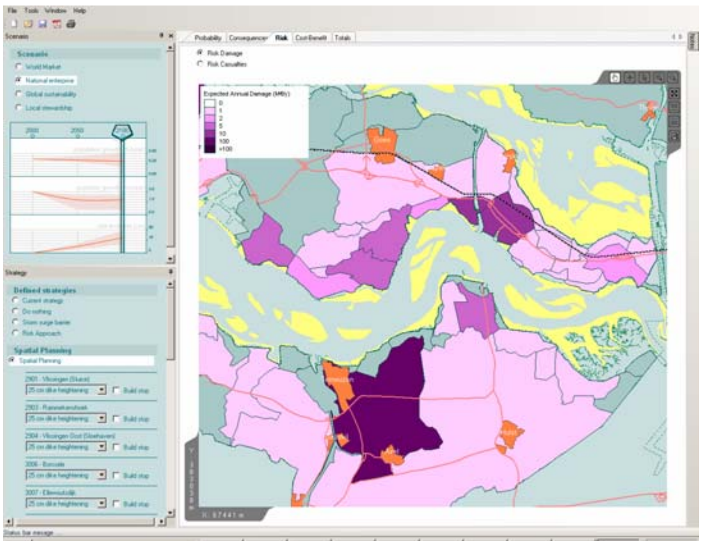


Figure 1. Screendump of DSS for the Schelde: scenarios are shown in the upper-left corner, strategies on the lower-left and the effect on expected annual damage (per subarea) on the right

DSS functionality

The following procedure is followed by the user of the DSS:

1. Explore the future
   How will the flood risk system change during the next century? The future (0-100 years ahead) is envisaged by scenarios that represent autonomous developments that cannot be influenced by the flood risk manager, such as sea level rise, economic growth and population growth. To support this exploration, the results of model calculations are stored in a database. This enhances a quick response to choices made by the user. These developments have an impact on the future flood probability, economic risk and casualty risk.

2. Choose your strategy
   What can be done to reduce the current and future flood risk? Compare strategies and assess the effect against criteria such as cost/benefit ratio, societal risk, environmental impact, etc.

3. Discuss your findings
   After exploring the future, the user will have insight in the concept of flood risk and the effect of different types of measures. Other users will have a different perspective on the preferred strategy (combination of measures). This third DSS component allows for a discussion between stakeholders, by comparing the combined effect of scenarios and strategies.

DSS applications

Two prototype DSSs have recently been developed:

– For the Schelde Estuary, under the framework of the European FLOODsite project (Gahey et al. 2008) (Figure 1);
– For the Netherlands, under the framework of the Dutch Water Safety 21st century project (Klis and Dijkman 2005) (Figure 2).

Conclusion

A first workshop with end-users showed that the DSS-concept is appreciated by a broad audience and that a high level of insight is reached. Using the DSS for the purpose of comparing safety standards was considered possible. This is promising in the context of the current political discussion about flood safety standards in the Netherlands.
In the coming years the prototype of WV21 will be further developed in close cooperation with the end-users (Ministry, provinces, water boards, etc.). An annual update of the system will ensure that the societal discussion about flood protection levels in the Netherlands is based on the latest scientific information about flooding probabilities, flooding impacts, climate change scenarios, socio-economic development scenarios and alternative measures and their effects.

References

Gahey, C. M., Luther, J., Mens, M., Petroschka, M., Sayers, P., Schanze, J., and Walz, U. (2008). Methodology for a DSS to support long-term flood risk management planning. FLOODsite.

Klis, H. v. d., and Dijkman, J. (2005). Haalbaarheidsstudie hulpmiddel veiligheidsdiscussie: Blokkendoos WV21. WL Delft Hydraulics, Delft.

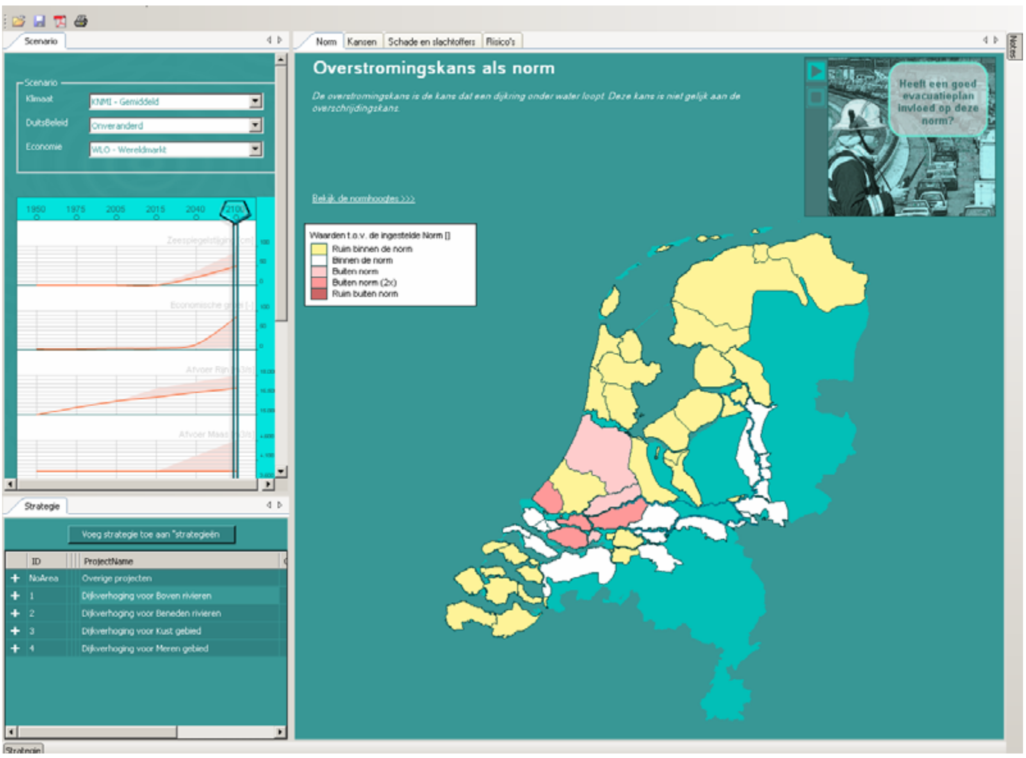


Figure 2. Screendump of DSS for the Netherlands: scenarios are shown in the upper-left corner, strategies on the lower-left and the effect on safety standards on the right

Identification and quantification of uncertainties in river models using expert elicitation

J.J. Warmink[1], H. van der Klis[2], M.J. Booij[1], S.J.M.H. Hulscher[1]
[1] *University of Twente, Water Engineering & Management, PO Box 217, 7500 AE Enschede, the Netherlands, j.j.warmink@utwente.nl*
[2] *Deltares, Delft, the Netherlands*

Abstract
The aim of this study is to identify the sources of uncertainty that induce the largest uncertainties in the model outcomes and quantify this uncertainty using expert elicitation. Analysis of expert opinions showed that the Qh-relation and the roughness predictor of the main channel cause the largest uncertainties for design water level computations. For effect studies, the floodplain topography, weir formulation and discretisation of floodplain topography induces the largest uncertainty.

Introduction
Hydraulic–morphological river models are applied to design and evaluate measures for purposes such as safety against flooding. These numerical models are all based on a deterministic approach. However, the modelling of river processes involves numerous uncertainties, resulting in uncertain model results. Uncertainty is defined as any deviation from the unachievable ideal of complete determinism (Walker et al., 2003). Uncertainty in models comprises (1) the difference between a model outcome and a measurement and (2) the possible variation around a computed value. Knowledge of the type and magnitude of these uncertainties is crucial for a meaningful interpretation of the model results. The aim of this study is to identify the sources of uncertainty that induce the largest uncertainties in the model outcomes and quantify this uncertainty using expert elicitation.

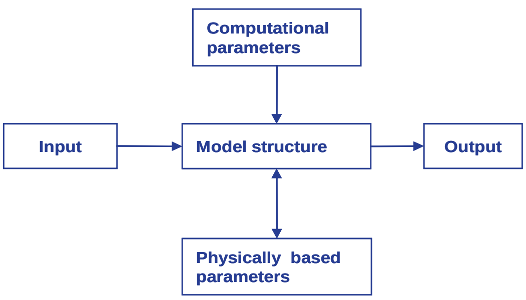


Figure 1. Possible locations of sources of uncertainty in a model that contribute to the model output uncertainty (based on Walker et al., 2003)

Method
The uncertainties in the model outcome are a result of the uncertainties of all parts of the model, called the sources of uncertainty. Figure shows a sketch of a general model. Uncertainties are present in the model input, parameters, computational parameters (e.g. grid size and time step) and model structure (Walker et al., 2003). In this study, the two-dimensional WAQUA model for the River Waal, used for the prediction of water levels is used as an example for the identification of sources of uncertainty.

Expert selection
At first 25 experts are asked for their experience with the WAQUA model. From these 25 experts, 16 are selected based on a Pedigree matrix (Funtowicz and Ravetz, 1990) with 4 criteria:

1. experience with code development,
2. experience with WAQUA projects,
3. number of years experience, and
4. number and type of publications about WAQUA.

On each criterion a score between 4 and 0 is given, based on the information given by the expert. Subsequently, the scores are normalised using a weight factor per criterion from 4 to 1 respectively. The 16 experts with the highest Pedigree scores are invited for an interview. Interviews are held with 11 of these experts. In this report, the results of only 7 experts are shown.

Expert interviews
The experts are asked to list the most important uncertainty sources. These are defined as the sources with the largest contribution to the model outcome uncertainties. The experts are asked to consider the following two situations:

1. the computation of design water levels (DWL), based on a design discharge wave and
2. the computation of the effect of a measure in the river bed, which is done using a constant discharge as input.

To compare the different experts, the experts are asked to comment on the sources of uncertainty on the same level of detail. Subsequently, the experts are asked to indicate the effect of a source of uncertainty on the computed water levels.

Results

The experts stated that the sources of uncertainty are different for the computation of the DWL and effect studies. In case of effect studies, the experts agreed that the sources of uncertainty that do not change between the computation with and without a measure have little influence on the uncertainty in the computed effect. In case of DWL computations, the uncertainties are dominated by the sources that are not compensated during calibration.

Uncertainties in design water levels

The uncertainty in the DWL computations for different sources is shown in Figure 2. Only the five largest sources of uncertainty in the DWL are shown. Clearly, the Qh-relation and the roughness predictor for the main channel have a relatively large uncertainty, according to the experts. Also the data used for calibration is mentioned as an important source. Besides the large values given for the order of magnitude of the uncertainty, also a large scatter is shown in the experts' opinions.

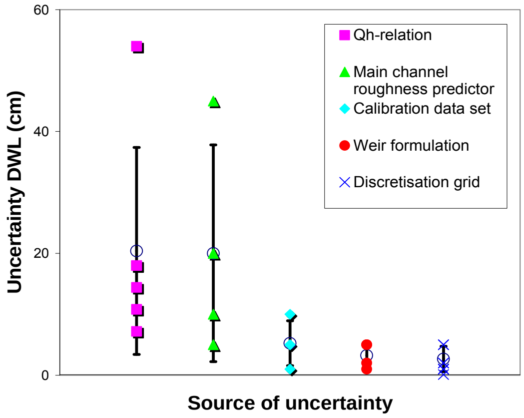


Figure 2. Uncertainty in computed design water level, due to different uncertainty sources. The mean (open circle) and the range of 1 standard deviation around the mean are given for each uncertainty source.

Uncertainties in effect studies

Regarding the uncertainties in effect studies (Figure 3), less experts were able to quantify the sources of uncertainty and the effect of uncertainty sources on model outcomes. This is mainly caused by the large dependency of the uncertainty on the location of the change in the river bed. In general, the uncertainty in an effect study is important if it is different in the situation with a measure compared to the reference situation. If, for example, many weirs are changed, the uncertainty due to weirs has a relatively large influence.

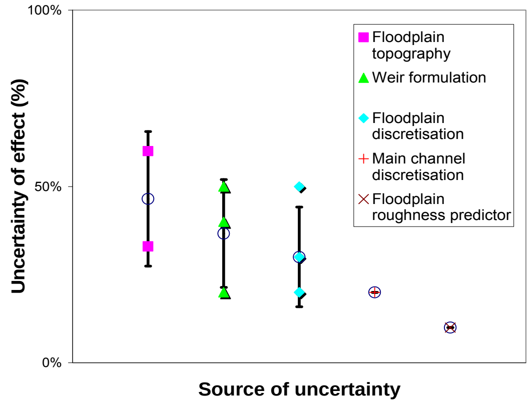


Figure 3. Sources of uncertainty for effect studies, expressed as a percentage of the computed effect. Also the mean (open circle) and the range of 1 standard deviation around the mean are given for each source of uncertainty.

Discussion

The experts are also asked for the uncertainty sources for other models than the WAQUA model for the Waal. They stated that the dominant source of uncertainty is determined by the characteristics of the flow field and river geometry. For example, the experts stated that the uncertainty in the main channel roughness is much larger than the uncertainty in the vegetation roughness. However, for the IJssel, the model outcome is more sensitive for vegetation roughness than for main channel roughness, because the floodplain areas are relatively large compared to the main channel.

Conclusions

It is concluded that:

– The Qh-relation and the roughness predictor of the main channel cause the largest uncertainties for DWL computations.
– For effect studies, the floodplain topography, weir formulation and discretisation of floodplain topography induces the largest uncertainty.

Acknowledgements

This research is supported by the Technology Foundation STW, and the technology program of the Ministry of Economic Affairs. The authors thank all experts for their time and constructive input in the preparation stage and during the interviews.

References

Funtowicz, S.O. and Ravetz, J.R. (1990) Uncertainty and Quality in Science for Policy. Dordrecht Kluwer, ISBN 0-7923-0799-2

Walker, W.E., Harremoës, P., Rotmans, J., Van der Sluijs, J.P., Van Asselt, M.B.A., Janssen, P.H.M. and Krayer von Kraus, M.P. (2003) Defining uncertainty, a conceptual basis for uncertainty management in model-based decision support. Integrated Assessment, 4(1): 5-17

HUP NL: probabilistic forecasting using Bayesian theory

J.S. Verkade[1,2], P.H.A.J.M. van Gelder[1], P. Reggiani[1,2]
[1] *Delft University of Technology, Department of Hydraulic Engineering, Stevinweg 1, 2628 CN Delft; j.s.verkade@tudelft.nl*
[2] *Deltares, Inland Water Systems division, PO Box 177, 2600 MH Delft; jan.verkade@deltares.nl*

Abstract
The Hydrologic Uncertainty Processor (HUP) quantifies the uncertainty about a hydrological forecast in terms of a probability distribution. This is done using the principle of Bayesian revision: prior (climatic) water level distributions are updated using information that is available at the forecast time, resulting in a predictive, posterior water level distribution. "HUP NL" predicts posterior distributions for water levels at Lobith, with lead times up to 96 hours. By linking the HUP with an operational forecasting system (FEWS NL), a prototype of an operational, probabilistic water level forecasting system was created.

Introduction
Future water levels are uncertain - this is the reason for forecasting. Forecasting, however, does not eliminate uncertainty but merely reduces it (Figure 1).

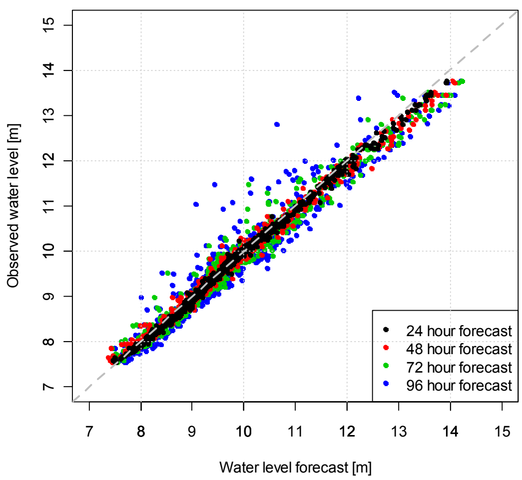


Figure 1. Reliability diagram for water level forecasts and observations

Probabilistic forecasts show that forecasts are not without uncertainty but, instead, explicitly express the certitude of a prediction. By doing so, they allow a user to set risk-based decisions. (Verkade 2008).

Objectives
The task of the HUP (Krzysztofowicz 1993; Krzysztofowicz 1999; Krzysztofowicz and Kelly 2000) is to supply posterior distributions of future water levels at Lobith conditional on the information that is available *after* a deterministic water level forecast is prepared:

$$\Phi\left(h_{n,Lobith} \mid s_{n,Lobith}, h_{0,Lobith}, h_{k,Cologne}\right) \qquad (1)$$

where

$h_{n,Lobith}$	future water level at Lobith
$s_{n,Lobith}$	deterministic water level forecast at Lobith
$h_{0,Lobith}$	current water level at the forecast point Lobith
$h_{k,Cologne}$	water level at Cologne, 24 hours *before* the forecast was made

The applicability of this method to probability forecasts in the Rhine was first explored by Reggiani and Weerts (2008). In the present study, the HUP was linked to a system that is used for operational, real-time forecasting, thus creating a prototype for an operational, real time, *probabilistic* forecasting system.

Results
Figure 2 shows a typical real-time probability forecast produced by HUP NL. From the centre outwards, the different colours indicate 50%, 80%, 90% and 98% confidence intervals respectively.

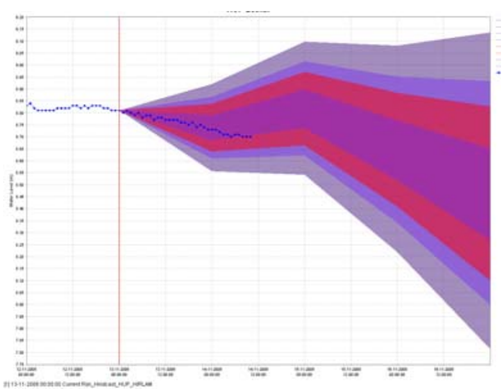


Figure 2. Typical probability forecast as produced by HUP NL

Forecast verification

For the purpose of verifying forecasts, the range of possible water levels was divided into eight bins (Table 1). Daily forecasts for a two-year period (2006 and 2007) were matched with observations.

Attribute diagrams

Attribute diagrams give a graphical depiction of the extent to which the forecasted probability of occurrence matches the actual frequency of occurrence of the event (Stanski, Wilson et al. 1989).

Attribute diagrams for HUP NL (of which Figure 3 is an example) show that, generally, the observed relative frequencies match forecast probabilities quite well, especially for those probability bins that contain large number of data points (as indicated by fractions near the plotting positions).

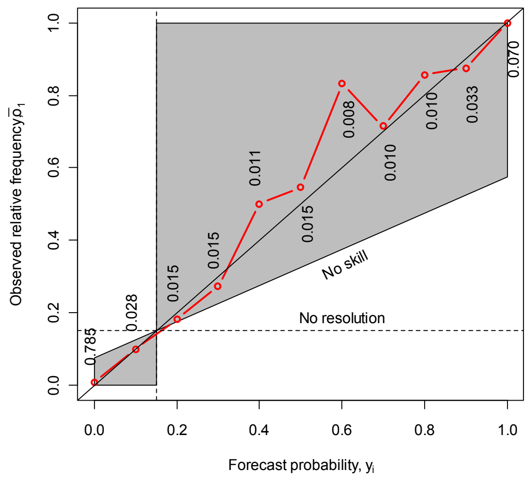


Figure 3. Attribute diagram for water levels between 10 and 11m, lead time 48 hours

Brier's probability score

Brier's probability score (Brier 1950) expresses the averaged square probability error of the forecast for binary forecasts. Brier scores of the forecasting system were compared to an unskilled, climatological forecast to determine the associated Brier *skill* scores (Table 1).

Table 1. Brier skill score (0 = no skill, 1 = perfect skill)

Bin	*24h*	*48h*	*72h*	*96h*
$6m < h \leq 8m$	0.92	0.86	0.79	0.69
$8m < h \leq 8.5m$	0.86	0.77	0.60	0.49
$8.5m < h \leq 9m$	0.86	0.80	0.64	0.48
$9m < h \leq 9.5m$	0.83	0.75	0.57	0.43
$9.5m < h \leq 10m$	0.80	0.69	0.55	0.37
$10m < h \leq 11m$	0.88	0.78	0.71	0.54
$11m < h \leq 12m$	0.88	0.80	0.66	0.48
$12m < h \leq 14m$	0.93	0.89	0.80	0.70

The Brier skill scores show that the forecasts are certainly skilled. As was to be expected, skill decreases with increasing lead time. It is also noticeable that skill scores are higher for bins at the lower and higher end of possible water levels. For these bins, the Brier score of the unskilled, climatological forecast is relatively low, making it 'easier' for the forecasting system to do well.

Verification results

Without exception, all measures show that the probability forecasts possess skill. Also without exception, they show that this skill decreases with increasing lead times, which was to be expected.

Although the skill scores are generally quite high, they are not 'perfect' and there is room for improvement. Skill scores may be used as a measure thereof.

Overall conclusion

By linking the Hydrological Uncertainty Processor to FEWS NL, a prototype of an operational, probabilistic water level forecasting system for the Rhine at Lobith was created. The system's performance was tested and found to be satisfactory. However, verification showed that there is room for further improvement.

Acknowledgements

The author wishes to acknowledge the useful comments by and discussions with Joost Beckers and Kathryn Roscoe, and the provision of data by Albrecht Weerts, all of Deltares.

References

Brier, G. W. (1950). "Verification of forecasts expressed in terms of probability." Monthly Weather Review **78**(1): 1-3.

Krzysztofowicz, R. (1993). "A theory of flood warning systems." Water Resources Research **29**(12): 3981-3994.

Krzysztofowicz, R. (1999). "Bayesian theory of probabilistic forecasting via deterministic hydrologic model." Water Resources Research **35**(9): 2739-2750.

Krzysztofowicz, R. and K. S. Kelly (2000). "Hydrologic uncertainty processor for probabilistic river stage forecasting." Water resources research **36**(11): 3265–3277.

Reggiani, P. and A. H. Weerts (2008). "A Bayesian approach to decision-making under uncertainty: an application to real-time forecasting in the river Rhine." Journal of Hydrology **356**: 56-69.

Stanski, H. R., L. J. Wilson, et al. (1989). Survey of common verification methods in meteorology, Environment Canada.

Verkade, J. S. (2008). On the value of flood warning systems. Delft, Deltares.

Bayesian Model averaging applied to FEWS NL

J.V.L. Beckers, K.L. Roscoe, J.F. Dhondia
Deltares, P.O. Box 177, 2600 MH, Delft, the Netherlands
Joost.Beckers@deltares.nl, Kathryn.Roscoe@deltares.nl, Juzer.Dhondia@deltares.nl

Abstract
Quantifying the uncertainty in forecast models is important for water management decisions. The Bayesian Model Averaging (BMA) method produces a probabilistic forecast from a collection of competing deterministic forecast models. The spread within and between the model-realisations is used to quantify the uncertainty of the overall forecast. The BMA method was applied to forecast models within FEWS NL, a water-level and discharge forecasting system for the Dutch rivers.

FEWS NL
FEWS NL is a Flood Early Warning System (Werner, 2004) for the Rhine basin. FEWS NL combines hydrological and hydraulic models with software for import, validation, interpolation and presentation of data. Every 30 minutes the system receives observed water levels from about 60 gauging stations in the Rhine basin. Every hour meteorological observations are downloaded from servers at the national Dutch (KNMI) and German (DWD) weather services for more than 600 stations in the basin of Rhine and Meuse. Additionally, the system uses output from four numerical weather models at KNMI, DWD and the European Centre for Medium Range Weather Forecasts (ECMWF). This weather information is processed by hydrological and hydraulic models to produce more than 70 individual discharge and water level forecasts.

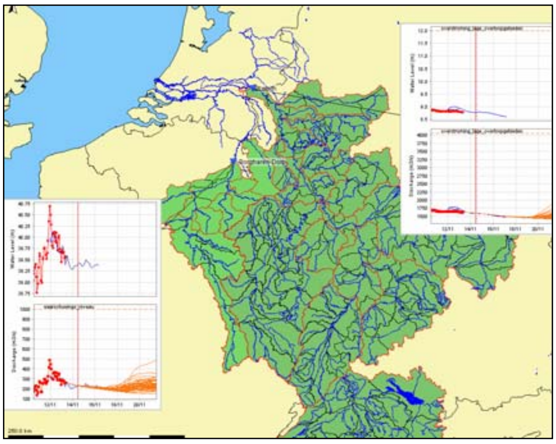


Figure 1. Model forecasts within FEWS NL.

Uncertainty in flood forecasting
Forecasts typically differ from the realized outcomes, with discrepancies between forecasts and outcomes reflecting the forecast error uncertainty. This uncertainty can be significant and varies between the different model forecasts. The uncertainty also increases with forecast horizon or lead time. Ignoring this forecast uncertainty leads to non-optimal management decisions (Pielke, 2003). Focusing attention on a single deterministic forecast leaves an operator overly vulnerable to both costly mistakes and the wasting of resources.

There is therefore a clear need for a method to quantify uncertainty of the forecast error. Several methods have been developed to do this (Beven, 1992, Krzysztofowicz 1999, 2000, Buizza, 1999). Here, we present results from applying Bayesian Model Averaging (BMA), which uses a training period, prior to the present forecast, to determine a correction for the bias and the uncertainty of the ensemble.

The BMA method
Bayesian Model Averaging (BMA) is a standard statistical approach for post-processing ensemble forecasts from multiple competing models (Laemer, 1978). It has been widely used in social and health sciences and was first applied to dynamical weather forecasting models by Raftery (2005). The basic idea is to generate an overall forecast Probability Distribution Function (PDF) by making a weighted average of the forecast PDF's from the individual models. The weights represent the estimated posterior model probabilities, i.e. the probability that a model will give the correct forecast PDF. In a dynamical model application, the weights are continuously updated and determined by investigating the performance of the competing models over a recent training period. In the current application this training period is typically one to two weeks.

Results

Below is a typical BMA forecast for the water level at Lobith. Note that the uncertainty bounds (10% and 90% probability of exceedance) increase with lead time.

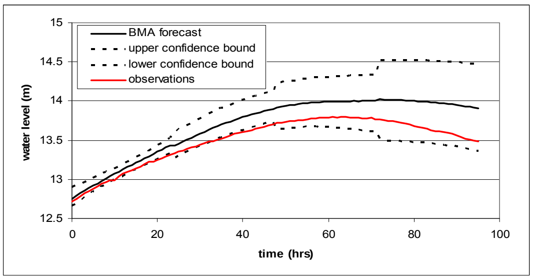


Figure 2. Typical BMA probabilistic water level forecast.

The quality of the BMA probabilistic forecast is assessed by several measures:

1. RMSE

The Root Mean Square Error (RMSE) of the BMA mean forecast is a measure of the accuracy of the forecast. For our water level at Lobith data series it was found that the BMA RMSE was significantly lower than the RMSE for each of the individual models.

BMA mean	Individual Models
5 cm	11-21 cm
7 cm	20-29 cm
11 cm	28-40 cm

Table1. RMSE values for the BMA mean forecast compared with the range of RMSE values for the individual model forecasts.

2. BSS

The Brier Skill Score (BSS) is a measure of the skill of the BMA probability forecasts relative to a reference, in this case a long term average probability (see Figure 3). A BSS of 0.9 is considered good.

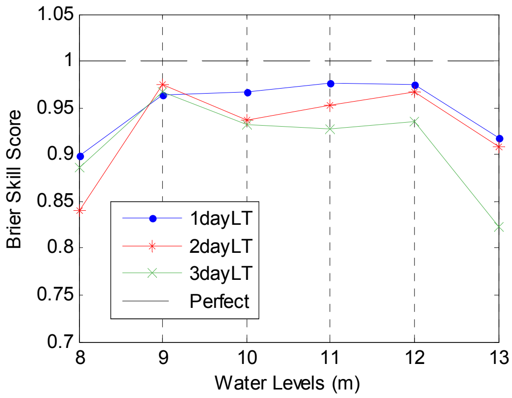


Figure 3. BSS of the BMA forecast for 1-3 day Lead Times

3. Quantile Plots

The quantile plot gives a measure of the reliability of the forecast probabilities, or quantiles (see Figure 4). The BMA quantile plots are close to the perfect 1:1 line.

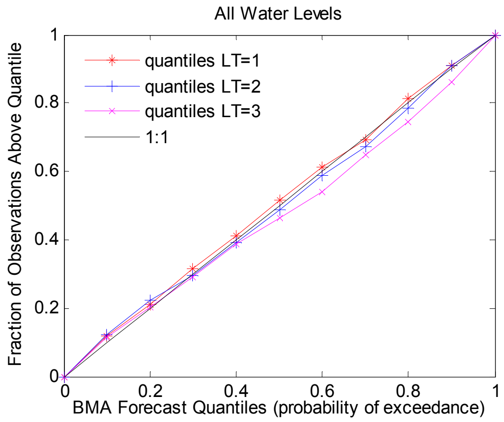


Figure 4. Quantile plot, comparing the BMA probability of exceedance and the observed occurrences, where the 1:1 line indicates a perfect forecast.

Conclusion

The BMA method produces an accurate and reliable probabilistic forecast. The RMSE of the BMA mean forecast is significantly lower than that of the best individual model in the series. The observed frequency of observations corresponds well to the forecast probability.

This work is partially financed by the FloodControl 2015 innovation programme.

Eric Sprokkereef and Jan Verkade are kindly acknowledged for contributing to this paper.

References

Beven, K.J. and Binley, A. (1992) Hydrol. Proc., 6 279.
Buizza, R., Miller, M. and Palmer, T. N. (1999) Stochastic representation of model uncertainties in the ECMWF Ensemble Prediction System. Quart. J. Roy. Meteor. Soc. 125, 2887–2908.
Leamer, E.E. (1978) Specification searches. Wiley, NY
Krzysztofowicz, R. (1999) Bayesian theory of probabilistic forecasting via deterministic hydrologic model. Water Resour. Res. 35, 2739.
Krzysztofowicz, R. and Herr, H.D. (2001) Hydrologic Uncertainty Processor for Probabilistic River Stage Forecasting: Precipitation-Dependent Model, Journal of Hydrology 249, 46.
Raftery, A.E., Gneiting, T., Balabdaoui, F. and Polakowski, M. (2005) Using BMA to Calibrate Forecast Ensembles. Mon. Weather Rev. 133: 1155.
Pielke R. A. and Richard T. (2003) Best Practices in Prediction for Decision-making. Ecology 84: 1351.
Werner, M.G.F., Van Dijk, M. and Schellekens, J. (2004) DELFT-FEWS: An open shell flood forecasting system. In: 6th Int. Conf. on Hydroinformatics, Liong, Phoon and Babovic (Eds.), World Scientific Publishing Company, Singapore. 1205-1

High resolution temperature measurements and hydraulic-energy balance modelling to quantify lateral inflows in a first order stream

M.C. Westhoff, T.A. Bogaard, H.H.G. Savenije
Water Resources Section, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, the Netherlands

Introduction

In order to locate and quantify lateral inflows into a first order stream, we used temperature as a tracer. We measured the temperature of the stream with a DTS (Distributed Temperature Sensing) fiber optic cable. The technique has a spatial resolution of 1 to 2 meter (depending on the system used) and a temporal resolution of 3 minutes with an accuracy of ~0.1°C. The fiber optic cable can be up to 10 km long.

Method

Four points of concentrated lateral inflow were identified and quantified by the DTS fiber optic (fig 1 and 2). If the temperature of the lateral inflow is known, the relative contribution of the inflow can be determined by a mass and energy balance.

$$Q_{Tot} = Q_1 + Q_2$$
$$T_{Tot}Q_{Tot} = T_1Q_1 + T_2Q_2$$

We applied 2 different methods to determine the temperature of the lateral inflows:
If the temperatures upstream and downstream of an inflow point are equal, the temperature of the lateral inflow should be the same. The net energy flux is zero here.
If the assumption is made that the temperature and the lateral inflow are constant over a certain period (typically a few hours), both the temperature and the contribution can be determined using a mass and energy balance for the start and the end of this period.

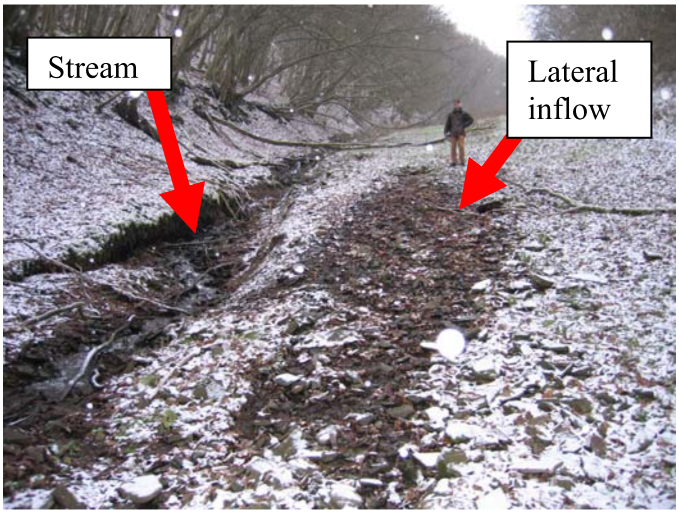


Fig 1. A point of lateral inflow, clearly visible due to snowmelt by this relative warm water

We also used independent temperature loggers for comparison.

Because temperature is not a conservative tracer we developed a combined dynamic hydraulic-energy balance model. The 1-D model calculates the energy balance including solar radiation (with shading effects), long wave radiation, latent heat, sensible heat and river bed conduction, taking the four point sources into account (fig 3).

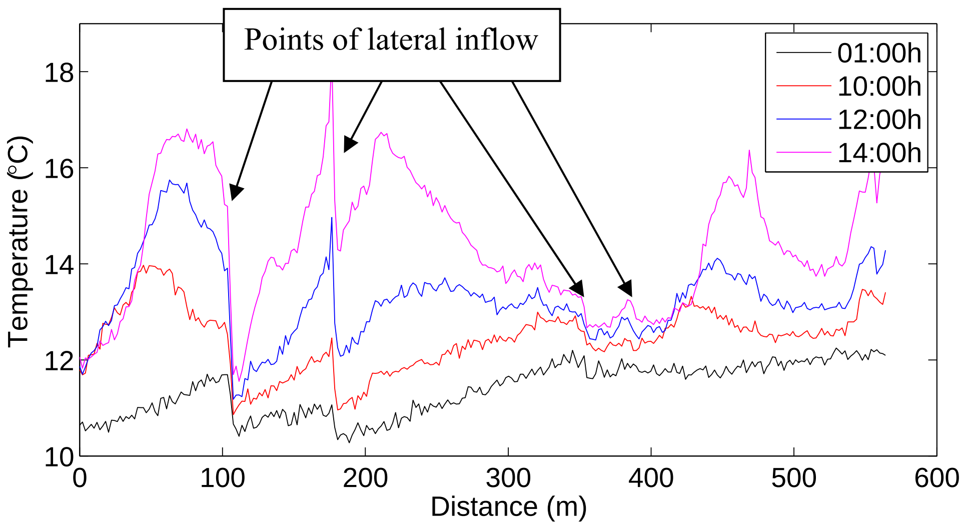


Fig 2. Temperature observations by DTS on June 21st, 2008

Besides the four point sources, diffuse sources and losses occur as well, varying over time. The hydraulic model and the energy balance model are used iteratively to quantify the diffuse sources and losses. It appeared that hyporheic exchange plays an important role in cooling the stream water. This flux can be quantified by mimicking the observed temperature along the stretch. The calibration was done for a steady state discharge.

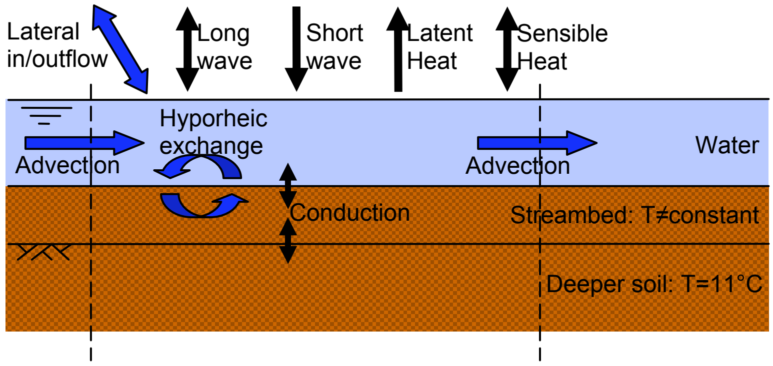


Fig 3. Schematisation of the energy balance model; the advection term, the depth and the lateral in/outflow are output data from the hydraulic model

Next step

Next step is to quantify different runoff processes during storm events, such as overland flow or rapid subsurface flow. The energy balance model is used for inverse modelling in order to quantify these sources.

Conclusion

The results from both measurements and modelling enhance the insight into the different discharge generation processes and the threshold levels at which they occur within a first order stream.

Analysing extreme discharges within the frame work of the Generator of Rainfall and Discharge Extremes (GRADE) project

N.L. Kramer, R.H. Passchier, J.L.V. Beckers, A.H. Weerts, M. Schroevers
Deltares, P.O. Box 177, 2600 MH Delft, the Netherlands, Nienke.Kramer@deltares.nl

Abstract
Generator of Rainfall and Discharge Extremes (GRADE) is a new methodology to provide a better physical basis for the estimation of the design discharge of the main Dutch rivers.
Within the framework of the GRADE project, the GRADE model for the river Meuse was validated using measurements. During this validation, it was found that the GRADE model underestimated the peak flows. The model was improved by calibrating the hydraulic model (HBV) for peak discharges, and accounting for daily time steps, which tend to underestimate peak values compared with hourly time steps.

Background GRADE
In the Netherlands the flood protection situation must be evaluated every 5 years, which includes the evaluation of the Hydraulic Boundary Conditions (HBC) along the Meuse and Rhine branches. For the determination of the HBC, use is made of the 1250-year design discharge at Lobith and Borgharen. The traditional estimation of the design discharges from statistical analyses of the measured peak discharges faces various problems. The estimation of the 1250-year discharge event from record of about 100 years involves a strong extrapolation, and is therefore hampered by a large uncertainty.

In 1996 Rijkswaterstaat RIZA, KNMI and WL | Delft Hydraulics started to work together on a new methodology to provide a better physical basis for the estimation of the design discharge of the main Dutch rivers. The first component of this new methodology is a stochastic multivariate weather generator, which generates long simultaneous records of daily rainfall and temperature records. The second component consists of hydrological and hydraulic models, which transform the generated rainfall and temperature records into discharge series. Altogether this new methodology is referred to GRADE: Generator of Rainfall and Discharge Extremes.
Advantages of the proposed methodology are that:

- long synthetic discharge records can be generated, reducing the need for extrapolation
- meteorological conditions and basin characteristics can be taken into account,
- the shape and duration of the flood can be analysed, it can potentially assess the effects of future development like climate change and upstream interventions such as retention
- basins and dike relocations. (De Wit and Buishand, 2007).

Validation GRADE Meuse
Within the framework of the GRADE project, the GRADE model for the river Meuse was validated. The outcome of this analysis was that the simulated (GRADE) peak discharges for Borgharen were lower than the measurements (Fig. 1). And therefore also lower than the traditional design discharge line ('werklijn') for the HBC 2006.

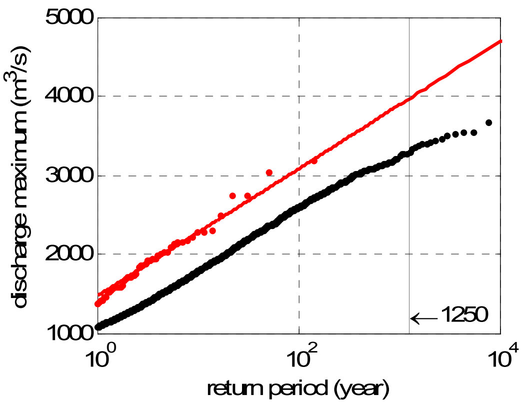


Figure 1. The red dots are the measured peak discharges for the river Meuse at Borgharen. The red line gives the traditional extrapolated design discharge line ('werklijn HBC 2006). The black dots are the peak discharges as determined with the original GRADE instrument.

To improve the GRADE instrument in this study, new HBV parameter sets were chosen. Secondly, a correction factor for the use of daily instead of hourly time steps was determined.

New parameter sets
The current calibration, as determined by Van Deursen (2004), gives good fit for 'low' and 'middle low' discharges, but the model was not calibrated for high discharges.
To improve the HBV model a calibration was carried out with the focus on peak discharges. For this calibration a GLUE method (Beven and Binley, 1992) was used. The GLUE method rejects the calibration concept of a single global optimum parameter set, but

instead accepts the existence of multiple acceptable parameter sets. Three fit-criteria were used to define the likelihood of each of the parameter sets:

- Nash-Sutcliffe efficiency coefficient
- Relative volume error
- Relative extreme value error.

The results of this GLUE analysis were an ensemble of more than 500 good parameter sets for the HBV model.

Five parameter sets were selected out of this ensemble of parameter sets. On these five parameter sets a second check was carried out, by validating them on historical storm events. Also out of this validation was concluded that the new selected parameter sets give good results. For most peak flows all selected parameters sets approximate the peak flows at Borgharen better than the original (Van Deursen) parameter set.

Peak discharge correction

To compare the flood frequency lines of the traditional method and the GRADE instrument, first the GRADE results have to be corrected for the use of daily values. This correction is needed, because GRADE uses daily time steps, where the traditional method uses measured hourly discharges. Generally, average daily peak discharges are lower than hourly peak values. In the GRADE study different flood events were studied. It was found that the most reliable way to calculate peak discharges from a daily averaged discharge peak at Borgharen is to multiply by 1.01 and add 80 m^3/s. This transformation differs less from the earlier-used correction of 70 m^3/s in the “Boertien II” reports.

Results

As described in the previous paragraph, five new parameter sets were selected and validated. A GRADE simulation of 3000 years was made using these new parameter sets. The results of GRADE were corrected with the daily-hourly peak discharge correction. The results are given in Fig.2. The 1/1250 design discharge of the 5 new parameter sets is situated between 3780 and 4260 m^3/s. The 1/1250 design as determined with the traditional method is 4000 m^3/s.

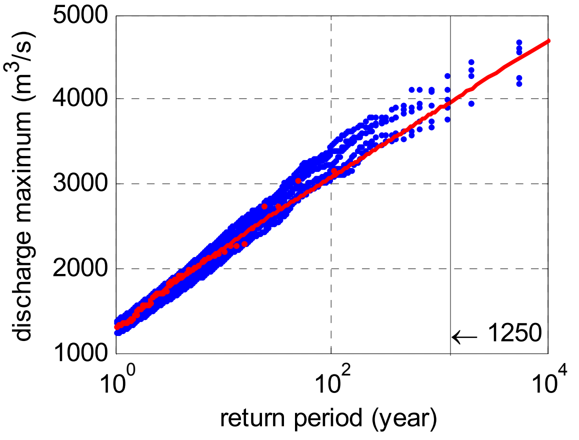


Figure 2. The red line is traditional design discharge line for the river Meuse at Borgharen, as determined for HBC2006. The red dots are the measurements. The blue lines are the GRADE results. It gives GRADE results for the 5 new selected parameter sets + peak discharge correction.

Conclusions and outlook

Using the peak discharge correction and the new parameter sets the GRADE results agree with the observations. Because of this good performance, these two corrections should be implemented in the new GRADE Meuse instrument.

In this study the GRADE instrument was focused on the river Meuse. As presented here, a validation was carried out. Secondly the uncertainties in this model were studied. The next step is to apply this knowledge in the GRADE model of the river Rhine.

Within the framework of the WTI project it is considered how the GRADE instrument can be used in the future. (Within WTI new HBC are derived every five years.) The GRADE instrument is now in the experimental phase. The new HBC will be calculated in 2010. For the official determination of these HBC, the traditional method will be used. However, GRADE will also be run to determine the HBC, although the results will not be used officially. When there is enough confidence in the model results, GRADE can be use operationally to determine the official HBC.

References

Beven, K., Binley, A. (1992) The future of distributed models: Model calibration and uncertainty prediction. Hydrological processes, 6, 279-298.

Deursen van, W. (2004) Afregelen HBV model Maasstroomgebied. Rapportage aan RIZA. Carthoga Consultancy. Rotterdam, The Netherlands.

Kramer, N.L., Schroevers, R. (2008) GRADE, deel F. WL Delft Hydraulics, Q4424.

Leander, R., Buishand, A. (2007) Rainfall generator for the Meuse basin. Description of 20.000 year simulation. KNMI.

A multidisciplinary Investigation of Runoff Generation Processes in Two experimental Headwater Basins in Luxembourg

S. Wrede[1,2], L. Pfister[1], A. Krein[1], J. Juilleret[1], T.A. Bogaard[2], H.H.G. Savenije[2] and S. Uhlenbrook[3]

[1] *Centre de Recherche Public - Gabriel Lippmann, 41, rue du Brill, L-4422 Belvaux, Luxembourg.*
[2] *Water Resources Section, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands.*
[3] *Department of Water Engineering, UNESCO-IHE, Westvest 7, 2611 AX Delft, The Netherlands.*
(contact: S.Wrede@tudelft.nl)

Introduction

In most river systems the majority of stream length comprises of headwater streams. These headwaters are located at the water-land interface and are conditional for water quality and hydrological response of large parts of the river basins. Traditionally, experimental hydrology has been focusing on the investigation of selected experimental headwater basins. However, a thorough assessment and systematic understanding of runoff generation processes of these “Aqua Incognita” (Bishop et al., 2008) at the headwater scale is still lacking and remains one of the major research goals in experimental hydrology.

To identify the main controls of runoff generation, this study investigates and compares two characteristic headwater catchments of the 297 km² Attert basin in the Grand Duchy of Luxembourg. The Attert basin is located at the contact zone between the schistose Ardennes massif (northern part) and the sedimentary Paris Basin (southern part). The headwater basins are considered as being relatively simple structured and representative of this contrasting lithology. While the forested Weierbach headwater basin (0.4 km²) is characteristic for the Devonian schist of the North, the partly forested Huewelerbach headwater basin (2.7 km²) reflects the lithology of the Jurassic sandstone and Triassic marls of the South (Figure 1).

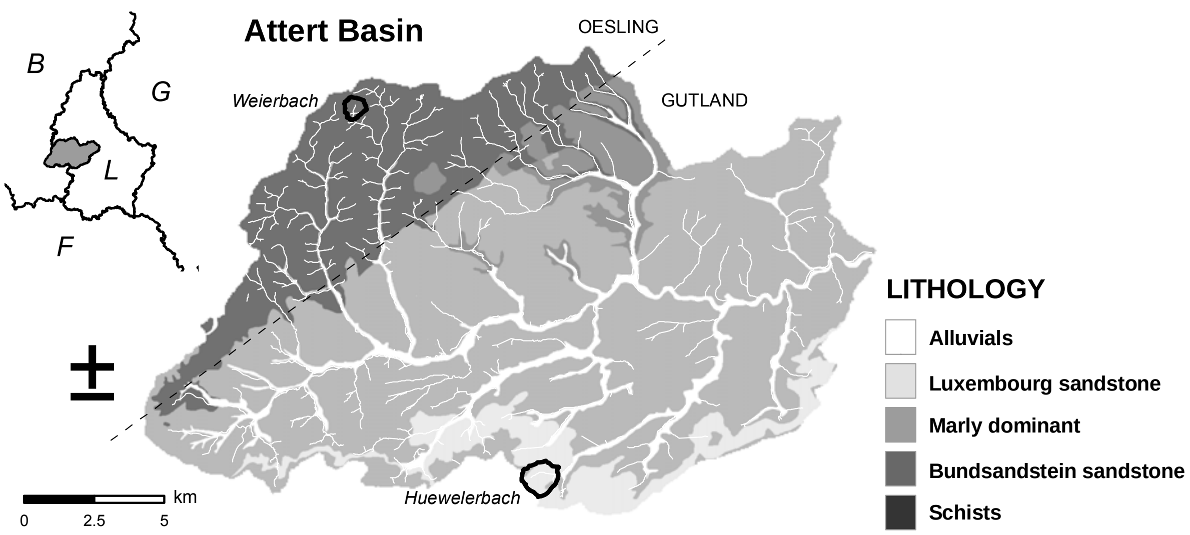


Figure 1. Location of headwater catchments in the Attert basin.

Methodology

The headwater research follows a multidisciplinary approach and combines traditional hydrological methods with partly new and innovative techniques from different disciplines: hydrology (i.e. hydrometry, geochemical and isotopic tracers), hydro geophysics (electrical resistivity tomography (ERT)) and pedology (soil drillings and sampling).

Results & Discussion

Preliminary results of the combination of investigation methods revealed more complex runoff generation processes than previously anticipated from traditional hydrological approaches. Different runoff components and hydrological responses could be identified by means of hydro chemical tracers and hydrometric data (Kies et al., 2005; Krein et al., 2007). The application of the ERT method further revealed the variable and complex subsurface configurations and their importance for runoff generation in the basins. These techniques helped in combination with drillings and soil sampling to better understand the origin and flow pathways in the catchment. While the sandstone basin is mainly characterised by a constant groundwater component occurring at the sandstone-marls interface and a fast rainfall-runoff reaction due to the presence of saturated surface flow on marly substratum, the hydrological response in the schist basin strongly differs. Here, the runoff generation is controlled by the impermeable bedrock topography and the depth of the saprolitic zone that supplies a dynamic and delayed shallow groundwater component (Van den Bos et al., 2006, Juilleret et al. 2008) (Figure 2).

Conclusions

The application of methods and perspectives from different disciplines proofed to be a valuable and complementary approach to gain a better insight into the catchment functioning and revealed the differences in hydrological and hydro chemical responses as a consequence of their geology.

Acknowledgements

The authors would like to thank the Ministry of Culture, Higher Education and Research of Luxembourg for the support of this research.

References

Bishop, K., Buffam, I., Erlandsson, M., Fölster, J., Laudon, H., Seibert, J. & Temnerud, J. (2008): "Aqua Incognita: the unknown headwaters". *Hydrological Processes*, 22(8), 1239-1242.

Juilleret, J., Hissler, C., Iffly, J.-F., Wrede, S., Pfister, L. & Hoffmann, L. (2008): "Un exemple de cartographie pédo-géologique couplée: le bassin versant expérimental du Huewelerbach au Luxembourg". *Archives de l'Institut Grand-Ducal de Luxembourg, Section des Sciences naturelles, physiques et mathématiques*, submitted.

Kies, A., Hofmann, H., Tosheva, Z., Hoffmann, L. & Pfister, L. (2005): "Using 222Rn for hydrograph separation in a micro basin (Luxembourg)". *Annals of Geophysics*, 48, 101-107.

Krein, A., Salvia-Castellvi, M., Iffly, J.-F., Barnich, F., Matgen, P., Van den Bos, R., Hoffmann, L., Pfister, L., Hofmann, H. & Kies, A. (2007): "Uncertainty in chemical hydrograph separation".- In: Pfister, L. & Hoffmann, L. (Hrsg. 2007): Uncertainties in the 'monitoring – conceptualisation – modelling' sequence of catchment research. *IHP-VI Technical Documents in Hydrology,* 81, Unesco, Paris, 21 - 26.

Van den Bos, R., Hoffmann, L., Juilleret, J., Matgen, P. & Pfister, L. (2006): "Regional runoff prediction through aggregation of first-order hydrological process knowledge: a case study". *Hydrological Science*

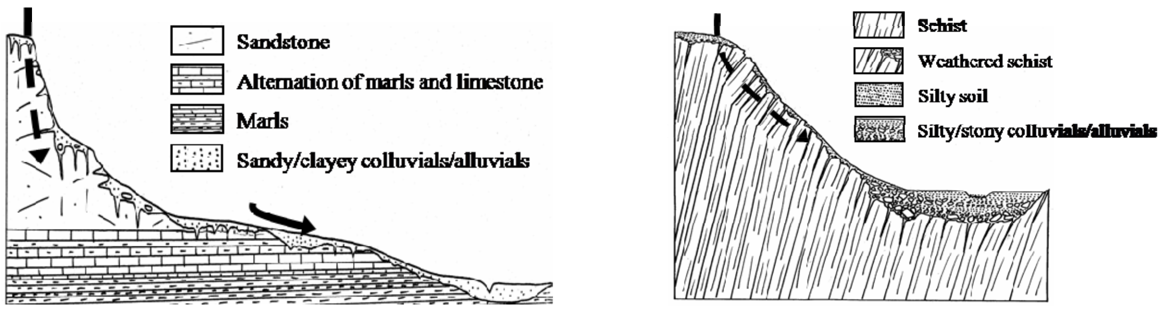


Figure 2. Schematized geology and runoff generation processes in the Huewelerbach (left) and Weierbach (right) catchments.

Model Predictive Control of the Discharge Distribution of the Rhine River in the Netherlands

M. Xu[1], P.J. van Overloop[1], R.M.J. Schielen[2], H. Havinga[2]
[1] *Section of Water Resources Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology*
[2] *Rijkswaterstaat, Water Dienst en Directie Oost-Nederland*

Introduction

The river Rhine is the one of the most important rivers in Europe. The river enters into the Netherlands from Germany at a small village called Lobith. After a few kilometres the river bifurcates into the Waal and Pannerdens canal. The water in the Pannerdens canal flows into the Nederrijn and IJssel at a second bifurcation point. At the moment the discharge distributions are regulated by the geometry of the bifurcation points. At high flow, the approximate distribution is 2/3 to the Waal, 2/9 to the Nederrijn and the remaining 1/9 to the Ijssel, assuming the total flow is 1. Figure 1 shows a schematic view of the water system.

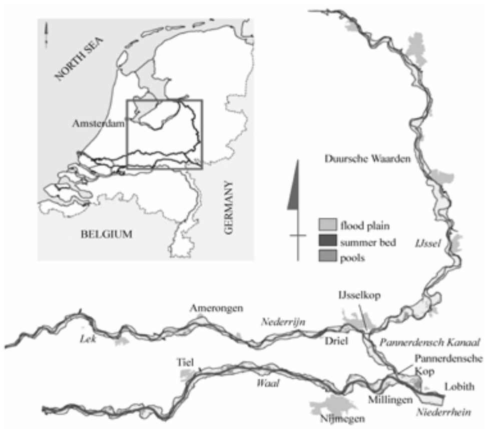


Figure 1. Schematic view of water system

It is important to maintain the discharge distribution during high flows otherwise it may create problems to the dikes and protected areas. This is because the dikes are designed for a specific design flood discharge. In addition, there exists an uncertainty of about 550 m^3/s in the assumed and actual discharge due to errors introduced by the estimation of roughness, morphological change, wind and model uncertainties. On the other hand the IJssel river branch has a function of navigation as well as it is used to flush the saline water in the northern part of the country. Therefore, during low flows the minimum flow towards the IJssel should be maintained. Based on the above-mentioned purposes, several bypasses are going to be constructed near the bifurcation points. Previous studies by Rijkswaterstaat and Delft University of Technology (Schielen R.M.J), proposed a dynamic control of the discharge to undertake these uncertainties. Particularly the Model Predictive Control (MPC) configuration is proposed for steering the discharge distributions, to manage extreme (low and high) flows and to counteract the effects of the uncertainties. The research aims at designing Model Predictive Control (MPC) in the Dutch Rhine water system. In this proceeding, MPC only applies on the first bypass between Bovenrijn and Pannerdens canal.

Method

MPC is an advanced control technique. The reason of choosing it is due to the factor of multi-objective water system subject to certain constraints. MPC can take advantage of the prediction with simplified model (Schuurmans, Bosgra et al. 1995) and optimization, and then allow the flexible management of the system. The schematic view of MP is shown in Figure 2.

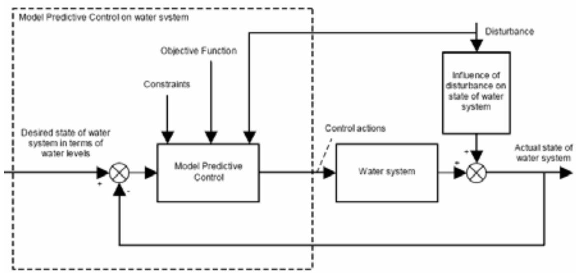


Figure 2. Schematic view of MPC (Van Overloop 2006)

The general objectives of the controller are:

1. eliminate uncertainties in the river during high flows until the design flow;
2. achieve the limited amount of water during low flows;
3. efficiently divert extra water into bypass during extreme flows above the design flow.

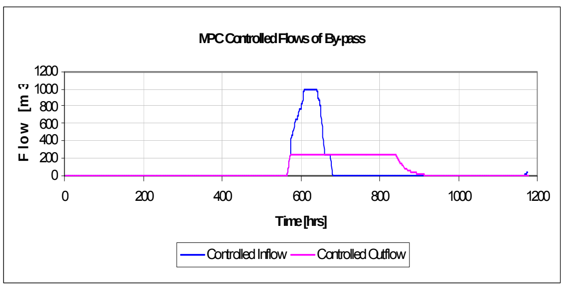


Figure 3. In and out flow through bypass

Results

The simulation runs for the extreme flow condition. Their results are illustrated through Figure 3 to 6. It is clear that MPC can divert certain peak flow into bypass under the constraints of river design flow, maximum in and out flow and maximum water level in the bypass. Although there are still some flow violations in the river shown in Figure 5, it is unavoidable, due to the limited bypass capacity (Figure 4). When comparing with feedback control, MPC cuts off the peak flow of 500m3/s more. See Figure 6. The reason behind it is that feedback acts when the river flow goes above the threshold, but when the real peak comes, there is no capacity to divert in the bypass. While MPC can predict the peak flow and optimally used the bypass capacity. The advantage of MPC is significant in this case.

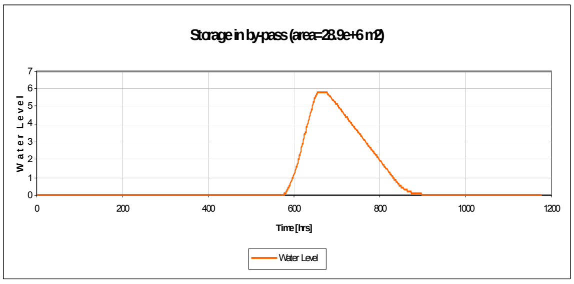


Figure 4. Water level in bypass

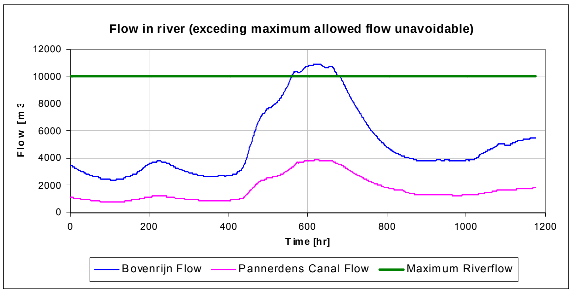


Figure 5. River flows

Reference

Schielen R.M.J, H. H., Lemans M. "Dynamic Control of the Discharge Distributions of the Rhine River in the Netherlands. (Draft)."

Schuurmans, J., O. H. Bosgra, et al. (1995). "Open-channel flow model approximation for controller design." Applied Mathematical Modelling 19(9): 525-530.

Van Overloop, P. J. (2006). Model Predictive Control on Open Water Systems, IOS Press.

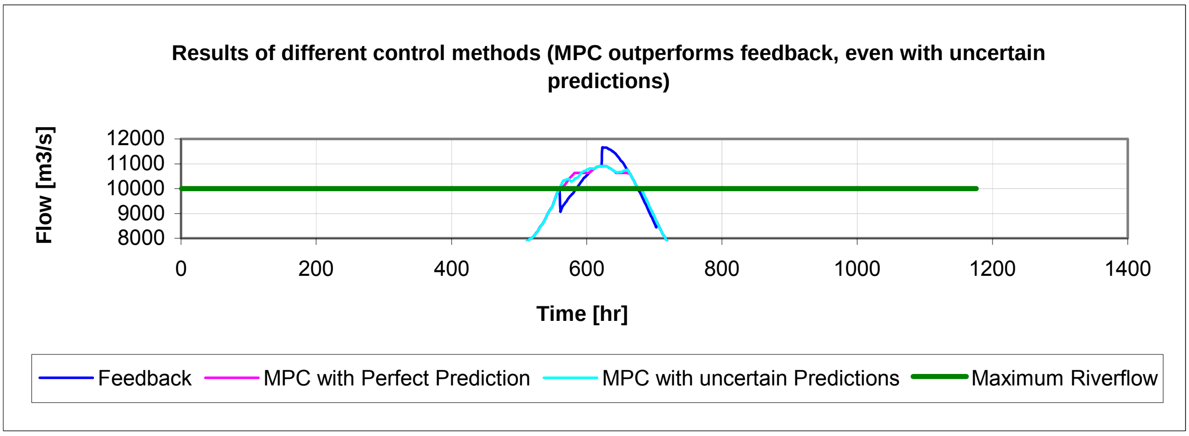


Figure 6. Feedback and MPC

Seasonal and long-term prediction of low flows in the Rhine Basin

M.C. Demirel, M.J. Booij and A.Y. Hoekstra
University of Twente, Water Engineering & Management, PO Box 217, 7500 AE Enschede, the Netherlands, m.c.demirel@utwente.nl

Abstract
The aim of this paper is to give information about a new project on the Rhine River. In this project we intent to identify appropriate low flow prediction models for the seasonal and long term by comparing uncertainties in low flows predicted by different pre-selected models.

Introduction
The study of low flow events may seem controversial for a low lying country like the Netherlands (Figure 1). However, low flow events in dry summers such as in 1969, 1976, 1985 and 2003 indicate the importance of considering these events in addition to flood events. Moreover, climate change is expected to increase the occurrence of low flows in the future. Therefore, the prediction of low flows for different lead times (seasonal term) and with climate change (long term) is of major importance. For the Rhine, there have been several attempts to predict low flows; however the results for longer lead times were mostly inaccurate and unreliable due to large uncertainties in weather predictions, model inputs and model structures.

The Dutch Water Service and the German Institute BfG are able to forecast low flows with a lead time of 4 days based on different hydrological and hydrodynamic models, e.g. FEWS, SOBEK, and WAVOS for the Rhine.

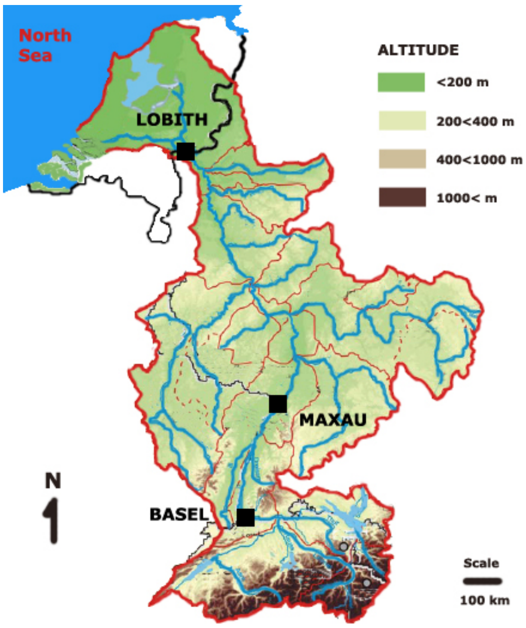


Figure 1. Rhine Basin

Seasonal predictions with a lead time of 2 weeks or 3 months do not exist (or exist without uncertainty quantification) although there is a high demand from different river-related functions (e.g. freight shipment, drinking water supply, and energy production).

Method
Hydrological models are usually compared based on their accuracy in simulating observed stream flow (Hurkmans et al. 2008; Te Linde et al. 2008). The uncertainties are usually not given with the results. Very few studies address model selection or applicability issues in seasonal predictions and climate change impact assessment. Klemes (1986) gave a plan for the systematic testing of applicability of hydrological models for impact assessment. Gleick (1986) reviewed different approaches for evaluating the regional hydrologic impacts of climate change and proposed a scheme for choosing an appropriate model. He indicated water balance models as more convenient for climate change studies. On the other hand, Klemes (1986) suggested models with a more physical basis that can be examined for different climate conditions such as dry and wet conditions.

In this study the uncertainty assessment in the model outcome will be used to determine the appropriate model (Figure 2) as the model output uncertainty integrates all other uncertainties related to input, parameters, and model structure. An appropriate low flow model is a model which produces output with the smallest uncertainty in low flows compared to other model alternatives. This uncertainty can also be compared with adequate uncertainty bands defined according to expert opinions to verify whether an appropriate low flow model also satisfies their requirements.

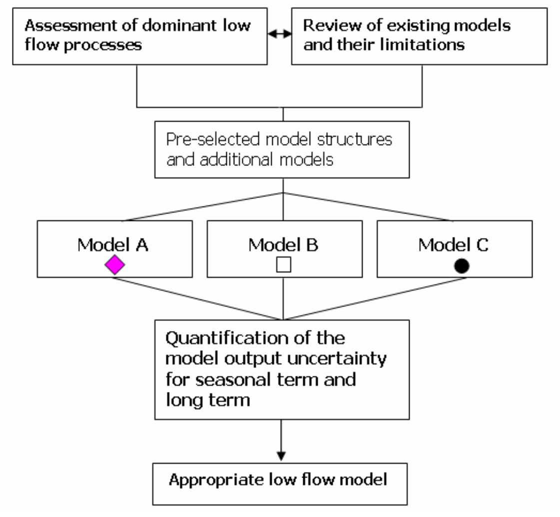


Figure 2. Preliminary research approach

The pre-selection of the models will be based on the identification of relevant low flow generating processes in the Rhine basin (for a particular lead time or climate impact assessment) and the availability of models incorporating these processes. Otherwise, additional models will be developed such as statistical and data driven models.

Results

The seasonal models are expected to produce more uncertainty than the current simulations for lead times of 1-4 days, since the uncertainty of the weather is much higher for longer lead times.

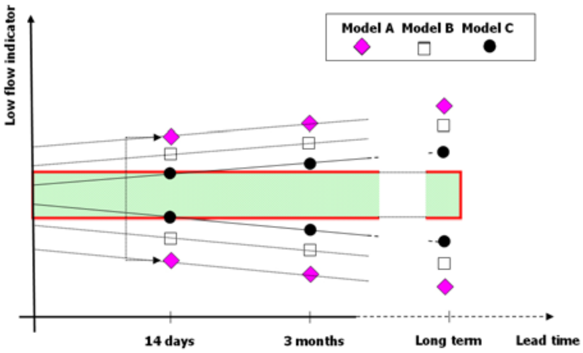


Figure 3. Identification of uncertainty bands at specific lead times for seasonal and long term low flow prediction.

Moreover the current hydrological models have been developed mostly for flood risk assessment which focuses more on fast overland flow processes than groundwater or base flow processes. These slower processes are usually represented by simple linear approaches. In consideration of these limitations and also other present model capabilities we intent to improve these models for longer lead times. We will present the uncertainty comparison of the prediction results like in Figure 3 to indicate the appropriate low flow model.

Discussion

We attended other scientific meetings and interviewed some experts about this new study which has a unique model evaluation scheme among the other classical simulation studies or model comparison approaches. The experts were asked for the most relevant low flow indicators in the Rhine basin. Moreover data availability and important spatial basin characteristics were also scrutinized. They underlined the groundwater relevance to low flow in the basin. The large area of the basin containing diverse regional processes and different seasonal behaviour within sub-basins will complicate the set-up and calibration of the models. The snow dominated upstream of Basel, the middle section of the basin in Germany and the Mosel River input need special attention in the modelling phase.

Conclusions

This projected study will shed a light on low flow aspects which is usually underexposed in hydrological modelling. It is important to improve and extend seasonal low flow predictions (including uncertainty) using appropriate models to support different river-related functions. The long term predictions will enable the assessment of the climate change impacts on low flows.

Acknowledgements

We acknowledge the financial support of the Dr. ir. Cornelis Lely Stichting (CLS), Project No. 20957310.

References

Gleick, P. H. (1986). "Methods for Evaluating the Regional Hydrologic Impacts of Global Climatic Changes." Journal of Hydrology **88** (1-2): 97-116.

Hurkmans, R., H. De Moel, J. Aerts and P. A. Troch (2008). "Water balance versus land surface model in the simulation of Rhine river discharges." Water Resources Research **44** (1): 14.

Klemes, V. (1986). "Operational Testing Of Hydrological Simulation-Models." Hydrological Sciences Journal **31**(1): 13-24.

Te Linde, A. H., J. Aerts, R. Hurkmans and M. Eberle (2008). "Comparing model performance of two rainfall-runoff models in the Rhine basin using different atmospheric forcing data sets." Hydrology and Earth System Sciences **12** (3): 943-957.

Improved base flow separation in lowland areas

A.L. Gonzales[1], J. Nonner[1], J. Heijkers[2] and S. Uhlenbrook[1]

[1] *UNESCO-IHE, Department of water engineering, PO Box 3015, 2601 DA Delft, the Netherlands*
[2] *Hoogheemraadschap de Stichtse Rijnlanden - HDSR, PO Box 550, 3990 GJ Houten, the Netherlands*
[*] *Corresponding author: Arpad Gonzales, gonza21@unesco-ihe.org, arpadgon@hotmail.com*

Abstract

Many studies for base flow separation exist, but few of them are focused on lowland areas. In this research, field observations and tracer experiments were applied in a lowland area in the Netherlands. Groundwater levels in the first aquifer show a fast reaction to precipitation events and are well correlated to discharges at the outlet. It was determined that approximately 80% of the total discharge is pre-event deep groundwater displaced by event water infiltrating in the northern part of the catchment, while approximately 10% is event shallow groundwater. Only the remaining 10% is rain water and overland flow. The rating curve method showed appropriate to separate groundwater from surface runoff when groundwater level measurements exist. Alternatively, the general recursive filtering method can be calibrated to give good results using the results of tracer experiments.

Introduction

Assessment of water resources coming from different storages and moving in different paths is important for its optimal use and protection, and for the prediction of floods and low flows. Moreover, understanding of the runoff generation processes is essential for assessing the impacts of changes (e.g. land use changes, climate change) on the hydrological response of the catchment (Uhlenbrook et al., 2008)

In many catchments, base flow is an important component of runoff. However, most of the studies up to the present focused on mountainous catchments, and little attention have been given to lowland areas. The objective of this paper is to show how the analysis of precipitation, water levels and discharges, together with tracer studies, and the use of different approaches for base flow separation can lead to a better understanding of the runoff generation processes and to the selection of an appropriate method for base flow separation in lowland areas.

Study area

The Langbroekerwetering is located in the central part of The Netherlands (see Fig. 1). Its climate is temperate, with a mean annual rainfall of 800 mm/a, and a mean annual potential evapotranspiration of 500 mm/a. The surface drainage system is dense and water leaves the area at various points due to the flat topography. Hydro geologically, the area comprises a series of alternating marine (clays, sandy clays) and fluvial deposits (coarse sands) overlain in the lowest areas by peat and clay deposits (covering layer), and limiting to the North with an ice pushed ridge.

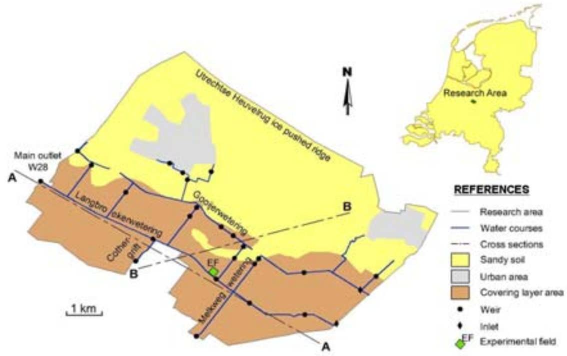


Figure 1. Location and overview of the study area

Methodology

In this research, field observations of precipitation, water levels and discharges, together with tracer studies are used to understand the runoff generation processes in the catchment. On the other hand, different tracer and non-tracer based base flow separation methods are applied and their results are compared.

Results

Rainfall, runoff and water level observations

A fast response of groundwater levels to rainfall events and a good correlation between levels in the first aquifer and discharges at the outlet are observed. The fast response of groundwater levels in the first aquifer may be the result of water infiltration in the northern part of the catchment where the covering layer is absent, according to an analysis of the pressure wave propagation.

Tracer-based separation

Two component separations using electric conductivity, calcium and magnesium show that approximately 80 % of the measured discharge is pre-event (ground) water (Fig. 3a). Separation using dissolved silica shows that 90% of the discharge at the outlet is groundwater. (Fig. 3b)

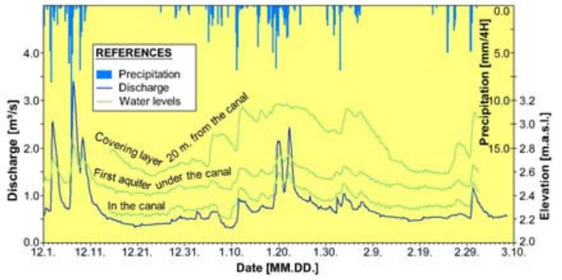


Figure 2. Precipitation, discharge and ground and surface water levels observed during the research period

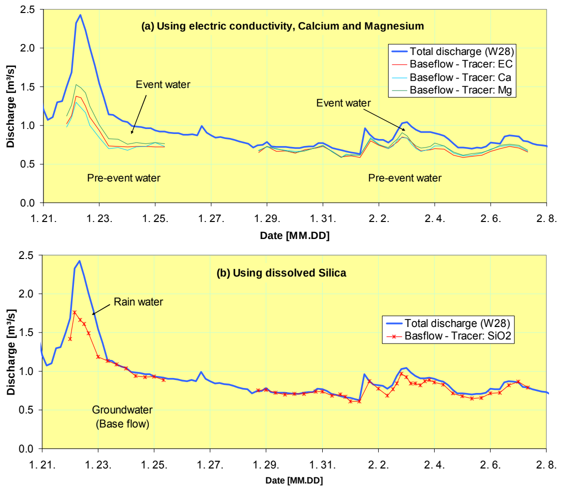


Figure 3. Two component tracer-based separations.

Non tracer base flow separation

The single graphical approach (Linsley et al., 1975) and the filtering methods Hysep 1, 2 and 3 (Sloto & Crouse, 1996) give high runoff coefficients (0.17 to 0.24). They separate fast and slow responses but not ground and surface water. (Fig. 4)

The unit hydrograph method (Su, 1995) performs a better separation between groundwater and surface runoff. Nevertheless, the method is subjective.

The rating curve method (Sellinger, 1996) and the general recursive filtering method (Eckhardt, 2005) calibrated with dissolved silica, give a good separation of groundwater.

Conclusions & Recommendations

In lowland areas, different non-tracer-based methods yield different separations. Then, tracer-based separations are an important tool to validate the selected method.

The rating curve method is appropriate to separate groundwater from surface runoff in lowland areas, and it can be used to monitor the effect of climate and land use changes.

The general recursive filtering method also gives good results when calibrated with the results of a reliable method e.g. tracer-based separation. However, if changes take place, the method should be re-calibrated.

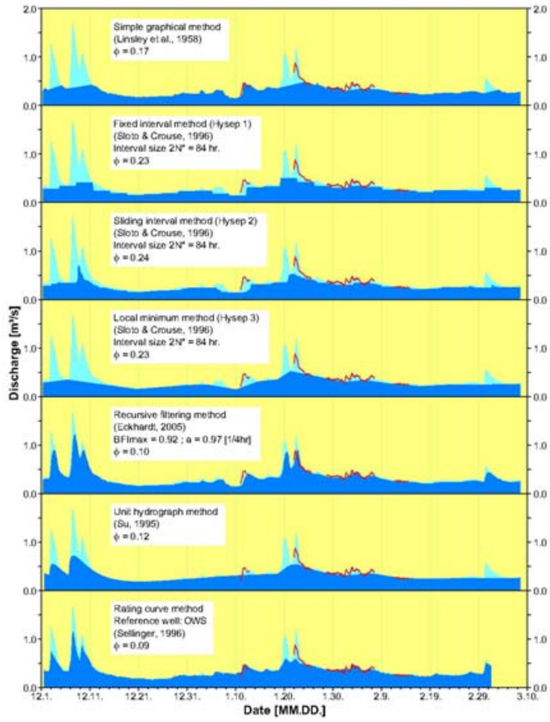


Figure 4. Base flow separation using non tracer based methods and comparison to groundwater separation with dissolved silica (red line).

It was assumed that the chemistry of overland flow is similar to rain water. Detailed studies are needed to prove this assumption and to asses the role of overland flow.

Acknowledgements

Acknowledgements. This study was supported and sponsored by the WaterMill Project and The Hoogheemraadschap de Stichtse Rijnlanden (HDSR). Additional data for this research was provided by HDSR, TNO, KNMI and by the Vrije University of Amsterdam.

References

Eckhardt, K. (2005) How to construct recursive digital filters for base flow separation. Hydrological Processes, 19: 507-515.
Linsley, R. K., M. A. Kohler & J. L. H. Paulhus (1975) Hydrology for engineers. McGraw-Hill.
Sellinger, C. E. (1996) Computer program for performing hydrograph separation using the rating curve method. United States Departament of Commerce National Oceanic and Atmospheric Administration.
Sloto, R. A. & M. Y. Crouse (1996) HYSEP: A computer program for stream flow hydrograph separation and analysis. U.S. Geological Service.
Su, N. (1995) The unit hydrograph model for hydrograph separation. Environment International 21(5): 509-515.
Uhlenbrook, S., J. Didszun & J. Wenninger (2008) Source areas and mixing of runoff components at the hillslope scale – A multitechnical approach. Hydrological Sciences Journal, 53(4): 741-753.

Modelling of a vanishing Hawaiian stream with DHSVM

R.P. Verger[1], D.C.M. Augustijn[1], M.J. Booij[1], A. Fares[2]

[1] *Department of Water Engineering and Management, University of Twente, P.O. Box 217, 7500 AE Enschede, the Netherlands; d.c.m.augustijn@utwente.nl*

[2] *Natural Resources and Environmental Management Department, University of Hawaii at Manoa, 1910 East-West Road, Honolulu, HI 96822, USA*

Abstract
Several Hawaiian streams show downward trends in stream flow. In this study Makaha Stream is investigated as an example. Three possible reasons are commonly mentioned for the discharge reduction: groundwater pumping, decreasing rainfall, and changes in vegetation. The effect of these factors on stream flow is evaluated with the model DHSVM. It appears that groundwater pumping is the most likely reason for stream flow reduction in Makaha Valley. To improve the model results more information about the complex volcanic underground is required.

Introduction
Hawaiian watersheds are relatively small, have steep terrains and are subject to heavy rainfall intensities which make them very sensitive to natural changes and anthropogenic influences. Fresh water resources for domestic, agricultural and industrial uses are very finite on small islands such as Hawaii. Therefore, it is extremely important to understand the hydrology of these small watersheds and the impact of any changes on them for their optimum water management. In recent years, stream flow of several Hawaiian streams has decreased. In this study Makaha Stream, located on the island Oahu (see Fig. 1), is taken as an example of a vanishing stream. Since 1990 the number of days Makaha Stream carries no water has increased from a few days to more than 100 days per year. To investigate the water balance of the Makaha watershed, the upper part of the watershed was modelled with the physically based Distributed Hydrology Soil Vegetation Model (DHSVM). Using this model, the impact of groundwater pumping, decreasing rainfall and changes in vegetation on stream flow was examined. These factors are considered possible causes for the decreasing discharge in Makaha Stream (Mair et al., 2007).

DHSVM
The Distributed Hydrology Soil Vegetation Model (DHSVM) was originally developed by Wigmosta et al. (1994, 2002) and simulates, at high spatial resolution, the dynamics in the land-related components of the hydrological cycle. DHSVM is typically used for water balance studies of small mountainous watersheds like Makaha Valley. For this study version 2.0 was used including a deep groundwater component (DHSVM, 2008). The available data of the upper part of Makaha Watershed (5.5 km^2) on topography, soil, vegetation, and meteorology were implemented in DHSVM using a 30 x 30 m grid and hourly time step.

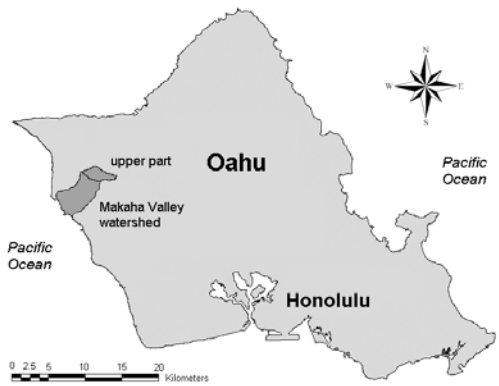


Figure 1. Location of Makaha Valley watershed on the Hawaiian island Oahu.

Calibration and validation
A complex model like DHSVM has many parameters that can be used for calibration. First, a sensitivity analysis was performed to identify the most useful parameters for calibration. Based on this sensitivity analysis the following parameters were selected for calibration: soil depth, base layer conductivity (for loss to deep groundwater), lateral conductivity of the soil, exponent for change of lateral conductivity with depth, and maximum infiltration rate. The model was calibrated for the period November 2005 through May 2006 by changing these parameters, in the order given above, from their default value until the best match was found between simulated and measured stream flow data. Because lateral conductivity and the exponent describing the change of this parameter with depth are likely to be interdependent, several combinations of these two parameters have been tried to find the best fit. The final calibration result is shown in Fig. 2. The fit is reasonable although the peaks are somewhat underestimated and the decline of the hydrograph after a peak is slightly too fast. The validation was done for the same period a year later. Unfortunately the model performance for the validation period was not as good as for the calibration period.

Table 1. Water balance (in mm) of reference situation (calibrated) and scenarios over the period November 2005-May 2006.

	Reference	Groundwater pumping	Rainfall (-15%)	Vegetation change
Initial storage	**1368**	**1368**	**1368**	**1368**
Final storage	**2097**	**2049**	**1965**	**2010**
Input (rainfall)	**1260**	**1260**	**1070**	**1260**
Output	**531**	**579**	**473**	**618**
Runoff	142	117	97	120
Evapotranspiration	389	389	367	498
Loss to deep groundwater	0.34	73	0.32	0.34

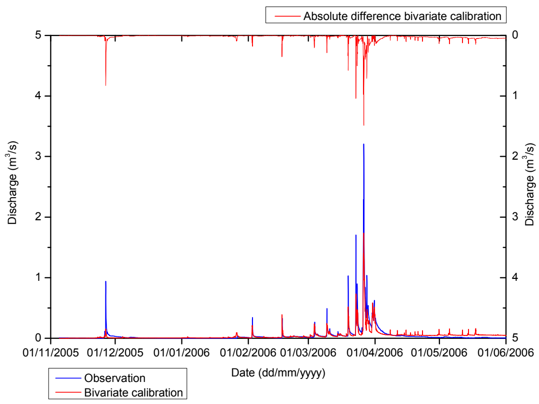


Figure 2. Observed and simulated discharge and absolute difference after calibration.

The calibration and validation could be further improved; however, the results were thought to be sufficient for the scenario analysis.

Scenario analysis

The calibration period was used to evaluate the impact of groundwater pumping, decreasing rainfall, and changes in vegetation on stream flow.

Groundwater pumping was simulated by changing the base layer conductivity such that the loss to deep groundwater increased to a total value of 73 mm over the simulated period, approximating the average amount of groundwater pumping since 1991.

Trends in rainfall in Makaha Valley have been studied by Mair et al. (2007). Between the pre-pumping (1960-1990) and the pumping period (1991-2005), mean annual rainfall at a gage near the outlet of the watershed decreased by 14%. A gage at the highest point in the watershed, however, showed a slight increase in rainfall of 2%. To investigate the effect of less rainfall, the rainfall was decreased with 15% over the entire area.

In Makaha Valley part of the native species has been taken over by invasive species that have different evaporation and interception characteristics. This has been modelled by changing the current vegetation of mainly forest and shrubs to evergreen forest which increased evaporation and decreased through fall.

Table 1 shows the water balance for each scenario. From the table it can be seen that all scenarios reduce the runoff. When looking at the hydrographs (not shown) it appears that lower rainfall mainly reduces the peak flow, while groundwater pumping reduces base flow. Changes in vegetation characteristics have little impact on the overall hydrograph.

Conclusions

Model results showed that base flow was most sensitive to groundwater abstraction, while peak flow was affected most by changes in rainfall. The influence of changes in vegetation characteristics on stream flow was negligible. Since base flow is the most continuous source of water, it is likely that groundwater pumping has a major contribution to the increased number of days that Makaha Stream carries no water.

The high resolution of DHSVM seems to be adequate to model a small mountainous watershed like Makaha Valley. The calibration can probably be improved by more advanced calibration techniques. Modelling the volcanic underground with complex dike systems, however, remains a problem due to lack of data.

References

DHSVM (2008) DHSVM website http://www.hydro.washington.edu/Lettenmaier/Models/DHSVM/index.shtml (last accessed November 2008)

Mair, A., A. Fares, and A. El-Kadi (2007) Effects of rainfall and groundwater pumping on stream flow in Makaha, Oahu, Hawaii. Journal of the American Water Resources Association 43(1):148-159.

Wigmosta, M.S., D.P. Lettenmaier, and L.W. Vail (1994) A distributed hydrology-vegetation model for complex terrain. Water Resources Research 30(6): 1665-1679.

Wigmosta, M.S., B. Nijssen, and P. Storck (2002) The distributed hydrology soil vegetation model. In: V.P. Sing and D. Frevert (eds.) Mathematical models of small watershed hydrology and applications. Water Resources Publications, p. 7-42.

Innovative acoustic Doppler current meter for measuring discharge in streams and small rivers

S.D. Kamminga[1], C.E. Meijer[1], S. Nylund[2], A. Lohrmann[2]
[1] *Qmetrix BV, Schipholweg 333a, 1171PL Badhoevedorp, the Netherlands, sicco.kamminga@qmetrix.nl*
[2] *Nortek AS, Vangkroken 2, N-1351 Rud, Norway*

Abstract
Traditional discharge measurements in smaller rivers and streams are performed with point-velocity sensors mounted on a wading rod which all have their disadvantages. We present an acoustic current meter which uses coherent Doppler technology in a hybrid processing scheme. A control box supports the user and computes discharge.

Introduction
Traditional discharge measurements in smaller rivers and streams are performed with point-velocity sensors mounted on a wading rod. A variety of sensors are available, including propellers, cup anemometers, electro-magnetic sensors and acoustic Doppler velocimeters. Each sensor technology has strength and weaknesses and requires the user to change sensor according to the specific conditions. Our aim with the present work is to develop a single acoustic current meter that can measure the 2D velocity vector in all conditions encountered by the hydrologists.

Method
We have developed a monostatic Doppler system operating at 6 MHz with the name ADC. Two acoustic beams are orientated at an angle of 10 degrees from the main axis and both the along-channel and cross-channel flow is calculated. The system has a velocity range from -0.2 to 2.4 m/s and uses a hybrid processing scheme to obtain precise measurements even on short time scales. The SNR is about 10 dB higher than when using the bistatic geometry of velocimeters, a benefit derived from a larger sampling volume (4 cm) and increased acoustic scattering at 180 degrees.
A pressure cell is mounted in the submerged sensor, Fig. 1, and gives the user precise information about the measurement depth. The sensor is connected via a cable to a handheld device (see Fig. 1) that controls the measurements, stores and displays data and presents the data on a graphical LCD display. The user can choose from more than 10 different calculation and control algorithms to assure national compliance when activating the discharge function in the software. Measured data can be offloaded to a PC for further processing.

Figure 1. Control Box box with graphical LCD display, operation support, discharge computation, data storage and internal rechargeable battery (Left). The submerge sensor with pressure cell for precise depth measurement, two acoustic transducers and a cable to the Control Box (right).

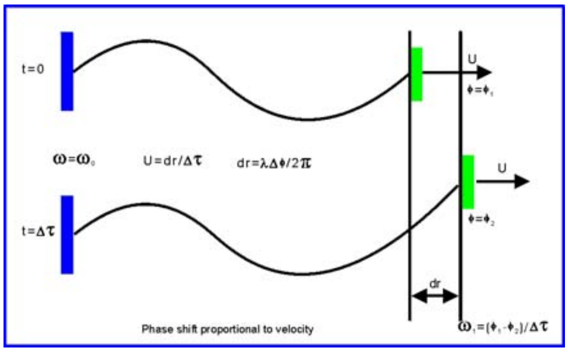


Figure 2. Principle of coherent velocity processing I

Coherent Velocity Processing
This method uses two or more acoustic pulses to estimate phase shift of returning echoes, Fig 2. Length of pulses and time between pulses can be chosen to optimize the design to the velocity range and accuracy. The time between pulse gives the maximum velocity as we cannot measure phase shift dΦ of more

than +/-pi. In the case of the ADC, we measure the distance dr = dΦ λ/ 2 pi the water has travelled in a time dτ. The velocity v is then dr/dτ. If a velocity v larger than the maximum velocity v_{max} is observed the measured phase dΦ is larger than pi and will be observed as dΦ – 2pi. This gives an apparent velocity of v – 2.v_{max}. The velocity v_{max} is therefore called the ambiguity velocity. In coherent velocity processing there is a trade-off between a large velocity range and a high accuracy.

Coherent Velocity Processing in the ADC

The ADC should be both accurate and have a large velocity range. It uses two sets of pulses to estimate phase shift. The first set of pulses has a larger velocity range. The velocity estimate of this set maps the phase shift of the second set of pulses onto a velocity range of -0.2 m/s to 2.4 m/s

The probe influences the upstream flow field so the velocity estimate is done in a two-step process. First, a coarse estimate is made close to the probe (about 5 cm away) and then a second, more precise estimate is made about 11 cm away from the probe.

Results

A series of tests have been performed. The temperature response, Fig. 3, shows a good behaviour which allows proper computation of sound velocity and correction of the pressure sensor response to temperature.

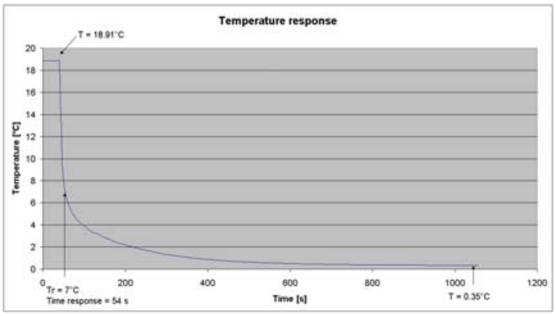


Figure 3. Temperature step response curve.

The pressure sensor shows a good linear response, Fig. 4 over the whole range of interest. Overall depth accuracy is better than 1 cm.

In a tow tank the velocity estimation was checked, Fig. 5, at 13 different tow speeds including experiments with the sensor measuring negative velocities. During these tests no seeding material was required.

Field tests have been performed in Germany and the Netherlands to check measurement accuracy and system performance under a range of conditions.

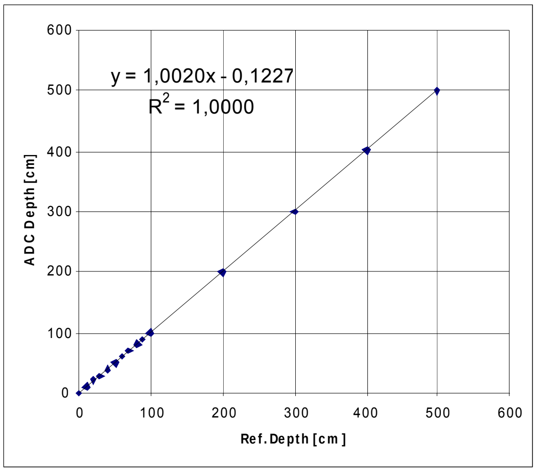


Figure 4. Pressure sensor linearity test result.

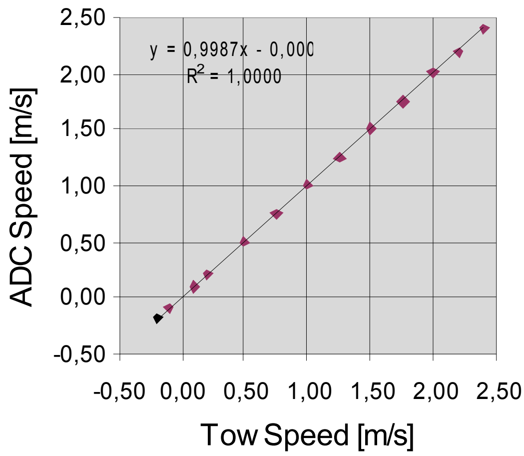


Figure 5. ADC measured velocity vs. speed of a towed vehicle.

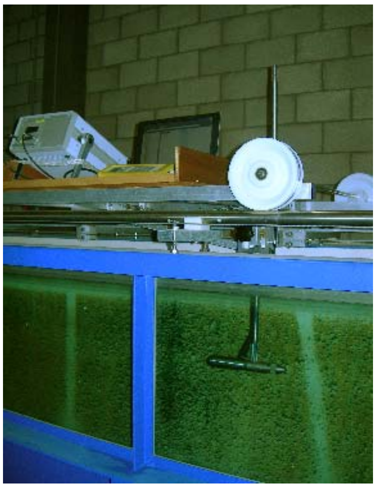


Figure 6. The vehicle on a towtank with the ADC sensor head in the water.

Conclusions

The applied coherent Doppler velocity processing scheme has resulted in an accurate instrument with a large velocity range. The user is support by a versatile control box.

Large Scale Bathymetric Survey of the River Meuse Along the Dutch/Belgium Border

S. Vos[1], R. Hoenjet[2]
[1] *Baars-CIPRO, Hoofdweg 16a, 1175 L.A. Lijnden; s.vos@baars-cipro.nl*
[2] *Rijkswaterstaat, dienst Limburg, Informatie- en Adviesdienst, Postbus 25, 6200 MA Maastricht, raymond.hoenjet@rws.nl*

Abstract
Major Dutch rivers are surveyed on a yearly or biyearly basis to provide bathymetric data and assess the sustainability of the rivers. The River Meuse between Maastricht and Stevensweert distinguishes itself from other major rivers due to its inaccessibility and its nature.
A wide scale bathymetric survey was conducted in February and August 2008 to determine the river morphology from the weir (low head dam) in Borgharen to Stevensweert. Specialized equipment such as the Interferometric Multibeam and the Robotic Total Station were used to obtain a 100 % coverage of the river bed morphology.
The results of the survey will be used for
1) improving the numerical river models of the Meuse,
2) assessing the stability of the weir at Borgharen,
3) reviewing the recently constructed gravel barriers and
4) monitoring the long-term riverbed morphology.

Introduction
One of the responsibilities of the Dutch Ministry of Public Works (represented by Rijkswaterstaat) is to maintain and preserve the major rivers of the Netherlands. The majority of the major rivers are surveyed on a yearly of biyearly basis to obtain up-to-date information. The surveys provide information about yearly changes of the river bed and the stability of riverbanks and submerged embankments. In addition, information is obtained about damages to underwater structures (such as protection structures) and navigational areas in the rivers.
The River Meuse North of Maastricht (Figure 1) (commonly referred as the Border Meuse) is the border between Belgium and the Netherlands. This river distinguished itself from other major rivers in that it is not easily accessible all year around. The mean discharge of the Meuse is 220 m^3/s and water depths are too shallow for survey vessels.
A bathymetric survey was conducted in February and August 2008 on the Border Meuse. Using specialized equipment (Interferometric Multibeam, Single Beam and Robotic Total Station) the main channel was surveyed in great detail to obtain a 100% coverage of the riverbed morphology.

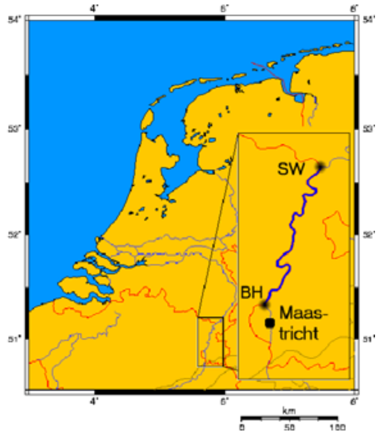


Figure 1. Overview of the survey area; the border Meuse river between Borgharen (BH) and Stevensweert (SW).

The River Border Meuse
The River Border Meuse between Borgharen (river km 15.4) and Stevensweert (river km 57) is a rain fed river. The area is destined to become a large river nature reserve under de European Habitat Framework where the river will have some freedom to develop its own course.

Discharges in the river range from 10 m^3/s during summer up to 2500-3000 m^3/s in extreme flooding cases. The discharge is regulated by a weir (low head barrier) near Borgharen and the minimum discharge is set at about 10m^3/s in order to preserve the nature in the river basin.
Water levels near Borgharen vary between 37m (low discharge) and 46m (extreme flood waves) above mean sea level.
As the river descends about 20 meters from Borgharen to Stevensweert some of the highest current velocities in the Netherlands are found in the Meuse. Velocities range from 0.25 m/s with low discharges up to 5 m/s with extreme high discharges.

Equipment
The survey on the Border Meuse was conducted with several techniques.

a) Interferometric multibeam
Interferometric multibeam systems (Lurton 2002) differ from standard multibeam systems in the ability to measure the riverbed topography up to the waterline with high detail and efficiency. In the narrow and deep main channel of the River Meuse this equipment proved very useful. A 250 Khz Geoswath Plus was used for the survey.

b) Robotic Total Station
A Robotic Total Station is a laser measurement device which automatically tracks and measures the position of a prism reflector at a pole in the order of millimetres. A Trimble S6 Total station was used for the survey.

c) Single Beam
A Single Beam survey was done behind the barrier where measurements with the Multi Beam and Robotic Total Station were not possible. A 200 Khz Ceeducer Single Beam was used for this area.

River survey
The survey on the Border Meuse was conducted in two stages.
The mainstay of the river was surveyed with an Interferometric Multi Beam on 16-23 January 2008. Only the first 500 m downstream of the weir could not be surveyed due to much turbulence in the water. Discharges in this period ranged from 600 m^3/s to 1000 m^3/s with current velocities up to 3 m/s. Due to the high velocities all measurements had to be done upstream in order to obtain sufficient measurements per square meter. The survey was confined to the main channel. The flooding areas were discarded.
The area down streams of the weir in Borgharen was surveyed on 22-23 August 2008. As discharges in this period were around 10 m^3/s large areas behind the weir could be accessed by foot and a small boat. The scour hole located about 100 m behind the weir was surveyed with Single Beam, whereas the area just behind the weir and the areas unreachable by boat were surveyed with the Robotic Total Station.

Results
The surveys of January and August 2008 have resulted in a complete survey of the Border Meuse from the weir in Borgharen up to Stevensweert. The survey produced a 1x1 m grid with 100% coverage.
These results are used by Rijkswaterstaat in various studies. The entire grid is used for models in the Flood Early Warning System (FEWS) to provide actual and up-to-date information about water levels during flooding.
Both 1-dimensional models such as SOBEK (Rijkswaterstaat / RIZA 2000) and 2-dimensional models such as WAQUA (Rijkswaterstaat / RIZA 2002) are used to asses flow patterns, bed shear stresses and multi-year development of the river bed.
The survey also provided detailed information about the riverbed. Both the recently constructed gravel bar (Figure 2) near river kilometre 31.5 and the area behind the weir (Figure 3) can be reviewed. Based on these measurements structural and stability checks can be done at the gravel barrier and the foundation of the weir.

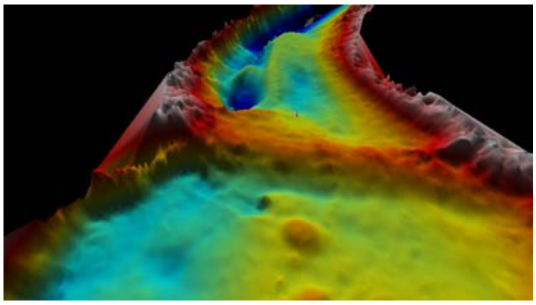


Figure 2. Gravel barrier in the Border Meuse near Maasmechelen (river km 31.5). The riverbed downstream (top of the picture) of the bar shows a large scour hole in the main stream channel.

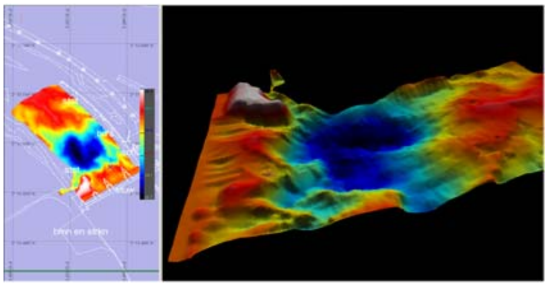


Figure 3. Riverbed downstream of the weir at Borgharen (left: reference map, right: 3d image) viewed from the north east side. The white area is a concrete basin, the red areas on the left are the weir structure with bottom protection. The blue area in the middle is the scour hole behind the weir.

Conclusions
The survey of January and August 2008 has provided much valuable information about the Border Meuse. The information is presently being used in various studies ranging from future flooding predictions to stability assessments. Results of these investigations will be available at a later stage.

References

Lurton, X., (2002), An Introduction to Acoustics; Principles and Applications. Springer and Praxis, 339p.
Rijkswaterstaat / RIZA: Bouw en calibratie SOBEK Maas versie 2000.1 t/m 2003.3m concept 7 december 2001
Rijkswaterstaat / RIZA: Kalibratie en verificatie van WAQUA-modellen, mei 2002.

Challenges in Modelling River Bends

W. Ottevanger*, W. van Balen
Civil Engineering and Geosciences, Delft University of Technology
**Corresponding author: w.ottevanger@tudelft.nl*

Introduction
Straight rivers are the exception rather than the rule. One focus of renaturalisation projects is to allow for the partial remeandering of rivers. Allowing rivers to behave more like uninhibited rivers in nature is expected to allow for more ecological diversity. Economic factors such as shipping and man-made infrastructure form boundary conditions for such renaturalisation projects. The spiral flow (see Figure 1) in river bends gives rise to a point bar along the inner bend which may form a bottleneck to ships, and bank-erosion along the outer bend may cause serious damage to man-made infrastructure along the river. Therefore a balance between economic and nature factors is needed. Numerical modelling may give insight into how the river system behaves.

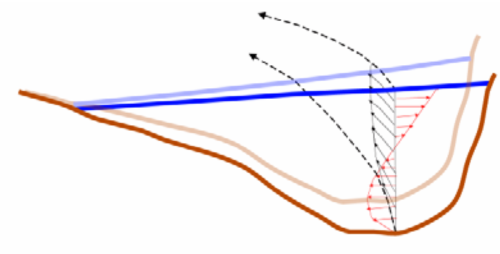


Figure 1. Stream wise flow (black) and spiral flow (red) in a schematized river bend turning to the left

Present numerical modelling at its highest level of detail can be done by solving the full Navier-Stokes equations (DNS). Large Eddy Simulation (LES) which is slightly less detailed is another good alternative. Due to unrealistic computation times and memory requirements, DNS and LES are not feasible at the scale of river reaches at this time (see Table 1).
This is especially true if we are interested in the morphological changes over many years. To study this we must resort to Reynolds Averaged Navier-Stokes (RANS) models or even depth-averaged RANS models (DRANS).

Table 1. Estimated grid dimensions required to simulate a fictive river stretch (length 10 km, width: 200 m, depth 5 m).

Numerical model	Grid dimensions L x W x D
DNS	$10^7 \times 2{\cdot}10^5 \times 5{\cdot}10^3$
LES	$10^5 \times 2{\cdot}10^3 \times 50$
RANS	1000 x 20 x 20
DRANS	1000 x 20 x 1

Method
We will consider numerical simulations of varying detail for two curved flume experiments (see Figure 2).The curved flume experiments can be seen as schematised river bends. The first experiment (Blokland, 1985) was done in a glass flume which was 0.5 m wide throughout. The flume had a straight inflow proceeding into a mildly curved 180 degree bend with a radius of curvature R=4.1 m and then a straight outflow section. The average discharge Q = 6.4 l/s and the average water depth H = 5 cm. The second experiment (Blanckaert, 2002) consisted of a straight inflow, followed by a sharply curved 193° bend with a radius of curvature R=1.7 m, and a straight outflow section. The width over the full length of the flume was 1.3 m. Q=89 l/s and H = 15.9 cm.

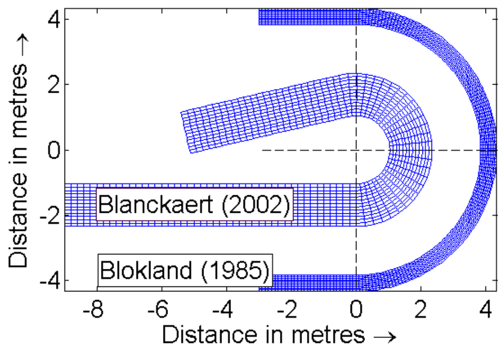


Figure 2. Numerical grids of Blokland and Blanckaert flume.

The numerical methods which will be used are:
1. LES,
2. RANS (RANS using a k-ε closure),
3. DRANS-L (linear spiral flow model),
4. DRANS-N (non-linear spiral flow model).

Theory
Assuming a logarithmic velocity profile in steam wise direction, an expression for the secondary motion (or 'spiral flow') can be derived from a simplified momentum equation. The main assumption (made here) is that interaction between main flow and spiral flow is negligible. The combination of these velocity profiles results in a dispersion stress which influences the conservation of momentum equation (Kalkwijk and De Vriend, 1980) and the direction of the bed-load transport near the bed (Struiksma *et.al.*, 1985).
DRANS-N no longer considers the interaction between the stream wise and spiral flow to be negligible. The spiral motion is calculated first

in the same way as in DRANS-L. After that the effect of the spiral flow on the main flow is included through a non-linear extension. The extension depends on the so-called bend parameter β (Blanckaert, 2002) given in (1) where C_f is the friction coefficient, v_s the stream wise velocity,

$$\beta = \left[C_f^{1.1} \left(\frac{H}{R} \right)^2 \left(\frac{\partial v_s / \partial n}{v_s / R} \bigg|_{n=0} + 1 \right) \right]^{0.25} \qquad (1)$$

n is the transverse channel coordinate (where n=0 denotes the channel axis). As shown in Figure 3 the spiral flow intensity is lower using DRANS-N for high values of the bend parameter. As the bend parameter gets large the stream wise velocity profile flattens as seen in the measurements by Blanckaert (2002), see Figure 4. Because of the vertical side walls in the flume a parabolic distribution of the spiral flow intensity over the width was imposed in DRANS-L and DRANS-N (Glasson, 2002).

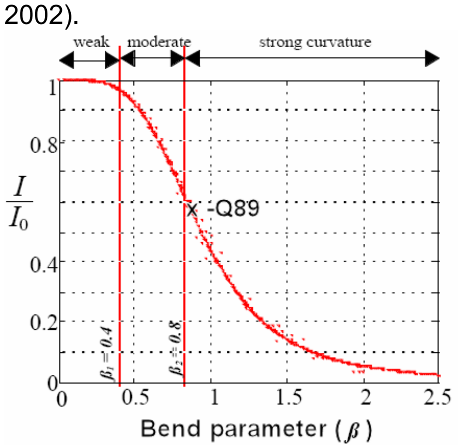


Figure 3. Ratio of spiral flow intensity calculated by DRANS-N over DRANS-L for varying bend parameter β (Blanckaert, 2002).

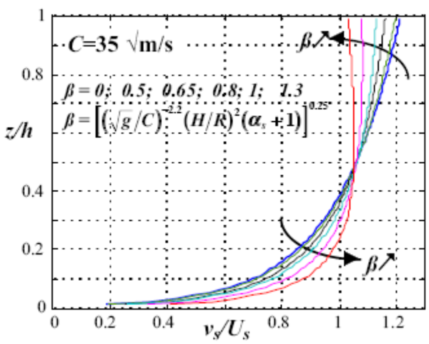


Figure 4. Stream wise velocity profiles for increasing bend parameters (Blanckaert, 2002).

Results and Conclusion

It can be seen (see Figure 5a) that in the mildly curved flume all the models are able to reasonably reproduce the velocity measurements. Near the side walls some improvement is necessary when using the DRANS-L and DRANS-N models.

The DRANS-N model results are the same as the DRANS-L model indicating that the effect of spiral motion on the main flow profile is indeed negligible. In the sharply curved flume (see Figure 5b) the DRANS-L overestimate the velocity in the outer bend, and underestimate the velocity in the inner bend. DRANS-N reproduces the outer bank velocity well but overestimates the inner bank velocity. The RANS and LES simulation are rather close to the measurements. Further investigation is therefore necessary to accurately model sharply curved bends, both near the banks as well as in the main channel.

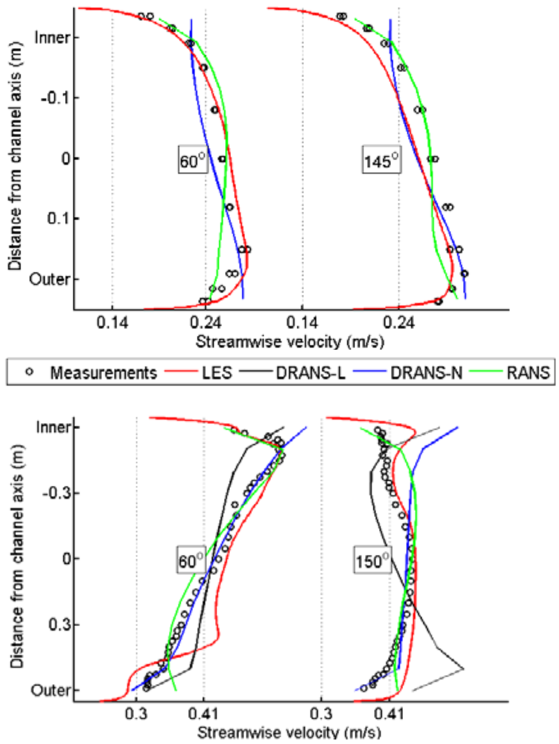


Figure 5. Measurements and simulated depth averaged stream wise velocities for the a) Blokland flume and b) the Blanckaert flume.

References

Blanckaert, K. (2002), Flow and turbulence in sharp open-channel bends, Ph.D. thesis Nr. 2545, Ecole Polytechnique Fédérale Lausanne, Switzerland. (ftp://lrhmac15.epfl.ch/Pub/Thesis/Blanckaert/PhD/)

Blokland, T. (1985), Turbulentie metingen in een gekromde goot, (Masters thesis) Afstudeer onderzoek, Rapport R/1985/H/7, Vakgroep Vloeistofmechanica, Afdeling Civiele Techniek, Technische Hogeschool Delft.

Glasson, L. (2002). A quasi-3D model for flow in open-channel bends, (Masters thesis) ENGEES (Strasbourg, France)— EPF (Lausanne, Switzerland).

Kalkwijk, J.P.Th., De Vriend, H.J. (1980) Computation of the flow in shallow river bends. Journal of Hydraulic Research, Vol. (18) No. 4: 327-342.

Struiksma, N., Oleson, K.W., Flokstra, C., De Vriend H.J. (1985) Bed deformation in curved alluvial channels. Journal of Hydraulic Research, Vol. (23) No. 1: 57-79.

Simple modelling of flow in a tidal river bend

D.H. Veenstra[1*], A.J.F. Hoitink[1,2], B. Vermeulen[1] and P.J.J.F. Torfs[1]
[1] *Hydrology and Water Management Group, Department of Environmental Sciences, Wageningen University, Droevendaalsesteeg 4, 6708 PB Wageningen (NL)*
[2] *Institute for Marine and Atmospheric Research, Department of Physical Geography, Utrecht University, P.O. Box 80115, 3508 TC Utrecht (NL)*
* *Corresponding author:* durk.veenstra@wur.nl

Abstract
With the aim to convert horizontal velocity profile measurements in a tidally influenced river bend to discharge estimates, a stationary 2DH bend flow model was further developed to account for river width variation. This has yielded a higher resemblance between measured and modelled longitudinal velocity profiles. Further improvement can be attained by accounting for turbulence-induced secondary currents, heterogeneous bed roughness and by adopting a non-stationary approach.

Introduction
Acoustic Doppler Current Profilers (ADCPs) can be mounted horizontally on a river bank, yielding single depth array velocity measurements in the horizontal plane across the river. For an ADCP mounted in a river bend in the Berau river, the acoustic signal reached up to 150 meters, which requires measurements to be extrapolated over about 250 m (Fig. 1).

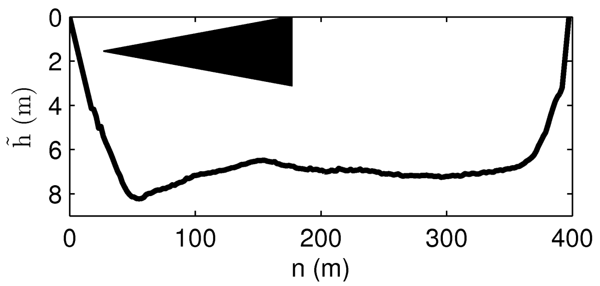


Figure 1. Black shaded triangle indicates the measurement range of the horizontal ADCP.

With the aim to allow for conversion of such ADCP measurements to discharge estimates, Vermeulen (2007) has setup a numerical 2DH bend flow model, which was kept as simple as possible, to allow for data assimilation techniques at a later stage. This model is loosely based on the work by Kalkwijk and De Vriend (1980), who use a closure sub model to account for helical flow. Vermeulen improved the numerical solution procedure to expand the application domain to sharply curved bends. However, Vermeulen's results compared still poorly to ship borne ADCP measurements. This was attributed to low quality bathymetry data and neglecting river width variation. This contribution extends the work of Vermeulen, by allowing for width variation in the model, and inclusion of a realistic bathymetry.

Method
A new, curvilinear, nearly orthogonal grid was constructed using the USGS SeaGrid software package, as depicted in top panel of Fig. 2. Bathymetry data was interpolated to this grid

using the SURFIS2D tool developed by Dutch Rijkswaterstaat, an interpolation software package supporting anisotropic interpolation directions such as in river bathymetry cases. The black line in the bottom panel of Fig. 2 shows the cross-section on which the horizontal ADCP is located.

The numerical setup of the model remained almost untouched compared to the work of Vermeulen (2007), although additional stabilizing measures were taken. This is next to linearization of the equations due to non-orthogonality of the grid.

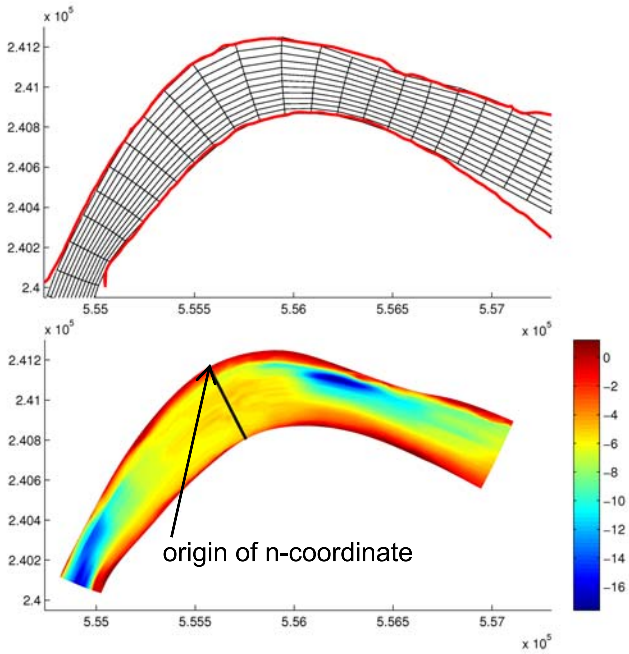


Figure 2. Top: image of numerical grid, actual grid is five times denser than displayed here. Bottom: interpolated bathymetry.

Results

By allowing for width variation, model sensitivity to bed roughness decreases and stream wise flow velocity gradually decreases with distance from the inner bank (Fig. 3a). This is largely in agreement with measurements (Fig. 3b) and relates to the gradual increase of longitudinal surface level slope towards the inner bend.

Velocity peaks in the outer bend can be attributed to the transport of momentum caused by secondary currents (Figs. 3c and 3d). During ebb flow, measurements feature an outer bend peak that is absent in the model results. During flood flow, measurements show an outer bend peak similar to that during ebb flow, which location is too close to the outer bank in the model results.

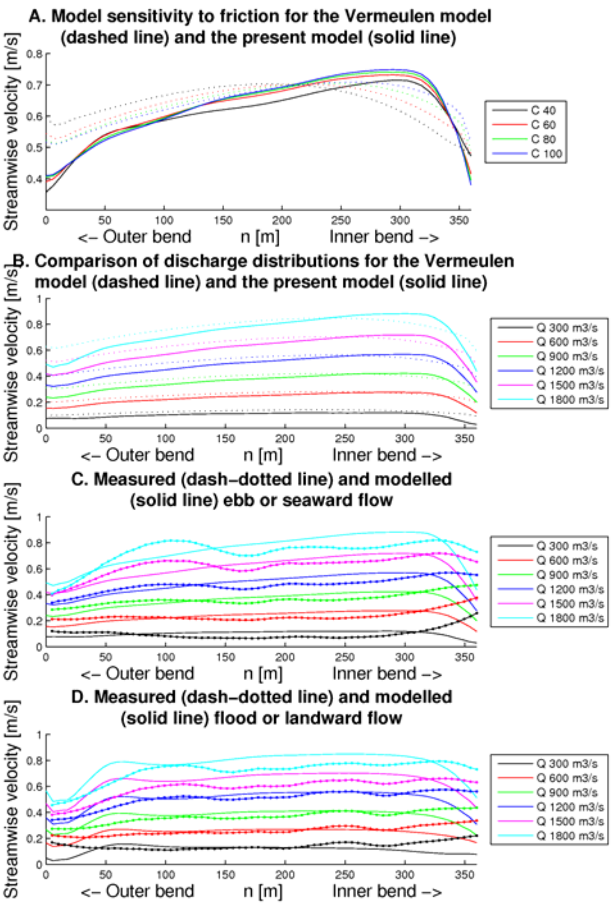


Figure 3. Top two graphs: comparisons of the present model to the results by Vermeulen (2007) regarding sensitivity to friction and discharge. Bottom two graphs: comparisons between modelled and measured velocity profiles during ebb and flood.

In general the modelled profiles lack details compared to measurements (Figs. 3c and 3d), which could partly relate to mismatches between modelled and measured secondary currents. There are other causes of secondary currents, such as anisotropy in turbulence, which are not accounted for. Another reason for velocity profile variation is the occurrence of bed forms, causing heterogeneous bed roughness. These morphological variations are included in the model bathymetry, but their effect on apparent roughness is improperly accounted for. Moreover, velocity variation in the central region of the bend lags behind velocity variation near the river banks. This is reflected in the stationary modelled profiles by both over- and underestimation of the measurements for different positions in the tidal cycle.

Conclusions

Transversal distribution of longitudinal momentum appears to be sensitive to channel widening, and allowing for width variation has brought the modelled velocity profiles closer to the corresponding measured velocity profiles. Nevertheless, the modelled velocity profiles still lack the details of the measurements, which can be caused by turbulence-induced secondary currents, heterogeneity of bed roughness and temporal effects.

References

Vermeulen (2007). Measuring tidal discharge in a river bend using a horizontal acoustic Doppler current profiler. MSc Thesis Hydrology and Quantitative Water Management Group, Wageningen University

Kalkwijk, J.P.T. and H.J. de Vriend (1980). Computation of the flow in shallow river bends. Journal of Hydraulic Research, 4:327–342

winner of the NCR-days presentation Award 2008

Bedform dimensions under supply limited conditions

A.P. Tuijnder, J.S. Ribberink
Water Engineering & Management, University of Twente, Enschede, the Netherlands; a.p.tuijnder@ctw.utwente.nl

Abstract
The volume of mobile sediment on the river bed is the primary control on the dimensions of the bed forms that develop. If an unlimited supply of sediment is available the bed form dimensions which develop are determined by the water depth, the flow velocity and the sediment characteristics. This relation is described by the various models for the prediction of bed form dimensions which have been formulated (e.g. Van Rijn, 1984, Zhang, 1999). When the volume of mobile sediment is smaller than the volume required for equilibrium dimensions, the bed forms are supply limited and will remain smaller.

Introduction
In rivers, bed load transport sometimes takes place over a layer of sediment that is not erodible. The volume of bed load on the coarse layer is small, if the supply of sediment from upstream to the armoured section is small, compared to the transport capacity. In this case only small bed forms can form and this results in a small bed form roughness. With an increase of the sediment supply relative to the transport capacity the volume present on the armour layer increases. This allows larger bed forms to develop and results in an increasing bed roughness. Bed forms are an important factor determining the resistance to flow of the riverbed and therefore they are an important factor determining the water levels. Very little quantitative data on the behaviour of dunes under supply limited conditions is available. Therefore we have studied the dependency of the bed form dimensions on the availability of sediment in flume experiments.

Experimental Set-up
For the experiments we used a sediment-recirculating flume (Fig. 1). The flume had a width of 1 m and a length of 30 m; the effective length for measurements of dune morphology was approximately 17.5 m. The slope of the flow could be varied, so it was possible to realize a uniform flow at the desired discharge and water depth.
A gravel layer was installed in the flume prior to the experiments. The gravel layer consisted of almost uniform gravel with 86% of the weight between 8 and 16 mm. The grain size of the gravel layer had been chosen such that it remained stable under the shear stresses observed in the experiments. The sediment that was transported over the coarse layer consisted of uniform quartz sand with a d50 of 0.8 mm.

Table 1. Hydraulic boundary conditions in experiments.

Series	h [m]	u [m/s]
1	0.20	0.52
2	0.30	0.52
3	0.15	0.52
4	0.20	0.58-0.67
5	0.20	0.46

The experiments formed five series, each with a constant water depth and flow velocity (Table 1). During each experiment the volume of sand remained constant because the sediment was recirculated. For each series, the volume of sand on the coarse layer increased with each experiment, thereby decreasing the supply limitation. The volume of sand - including pores - on the coarse layer is expressed per square meter as the average layer thickness d (Fig. 2 and 3).

Results
Figure 2 shows a height map of a section of 5 m from the laser surface scans. Fig. 2 Exp. 1-1, shows a scan of the gravel layer. In Exp. 1-3, a layer sand of 1 cm in depth had been distributed over the coarse layer. The morphological pattern that emerged in the sand layer during the experiment is visible in Fig. 3 Exp. 1-3. Two flow parallel stripes formed where the sand transport concentrated. Ripple-like bed forms are present in the stripes. In Exp. 1-5, which had the same flow conditions, the sand layer thickness has been increased again with 1 cm.

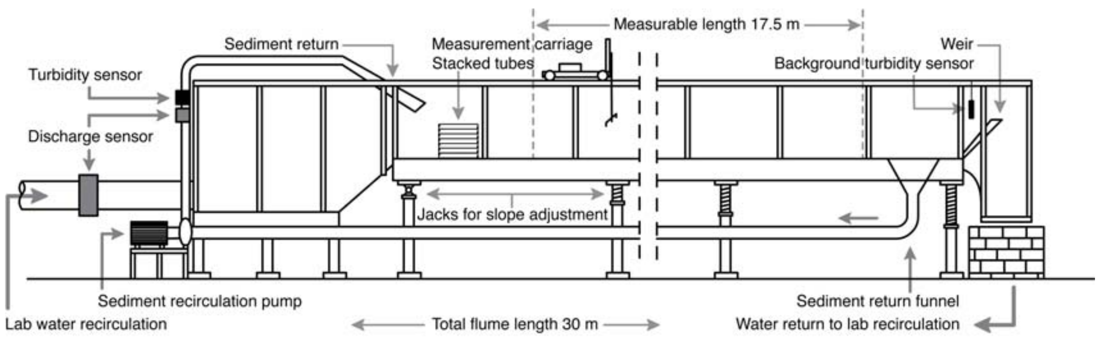


Figure 1. The set-up used for the experiments

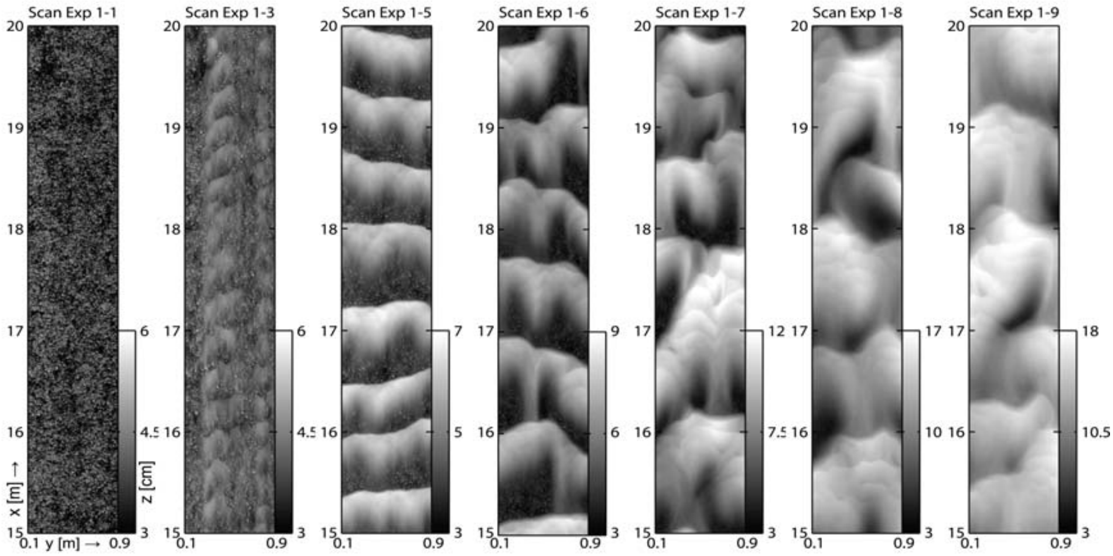


Figure 2. Topography after the experiments from Series 1.

The layer thickness in these experiments was: Exp 1-:1 0 cm, Exp 1-3: 0.3 cm, Exp 1-5: 1.1 cm, Exp 1-6: 2.0 cm, Exp 1-7: 4.1 cm, Exp 1-8: 7.0 cm, and Exp 1-9: 9.7 cm

In this experiment, straight-crested dunes appeared with a very regular topography. When we continued adding more sand, the bed forms grew bigger and became more irregular. This is illustrated in Fig. 2 Exp 1-6 - 1-9 by the disappearance of the straight crests, the appearance of the overlapping of dunes and the development of secondary bed forms on top of the larger dunes. With an increasing sand layer thickness, the influence of the coarse layer vanished and the dune dimensions increase to the alluvial dunes dimensions. In the other series (Series 2 to 5), the same experiments were performed at water depths and flow velocities different from those in Series 1. In these series similar trends were observed as will be shown in the following section where the relation of the bed form dimensions with thickness of the sand layer is explored.

Bedform dimension reduction

Using the data gathered in the experiments, the relation between the average active layer thickness and the dune dimensions has been studied. Figure 3 shows the measured dune heights (Δ) against the active layer thickness. Both axes have been made dimensionless by dividing by the alluvial dune height (Δ_0). It can be seen that although the series were done using different hydraulic boundary conditions, the results from all series collapse to one relation. This relation can be expressed using the function:

$$\frac{\Delta}{\Delta_0} = 1 - \exp\left(\frac{-d}{\alpha_h \Delta_0}\right)$$

This function is plotted as a solid line in Fig. 3. The parameter α_h determines the rate of growth of the dunes with increasing sediment supply. For dune length a similar relation has been derived. The series Dreano 1 and 2 are results from experiments using a similar setup but with much smaller dimensions (Dreano et al., 2008). This data also plots on the same line. This indicates that the relation also works for much smaller dimensions and may be scale independent.

Conclusions

A reduction function for the bed form dimensions under supply limited conditions has been derived using the experimental results. This function extends the use of bed form dimensions predictors to supply limited conditions.

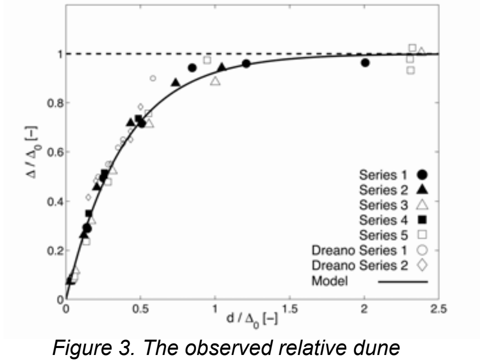


Figure 3. The observed relative dune

References

Dreano, J., Valance, A., Cassar, C., and Lague, D. (2008) Experimental study of deposit morphology and sediment transport in a flume. Proceedings Marine and River Dune Dynamics 1-3 April 2008 Leeds U.K., 97-102.

Van Rijn, L. C. (1984) Sediment Transport, Part III: Bed Forms and Alluvial Roughness. J. Hydraul. Eng., 110(12), 1733-1754.

Zhang, Y. (1999) Bed form geometry and friction factor of flow over a bed covered by dunes. PhD Thesis, University of Windsor.

A more extensive description of this work has been submitted to sedimentology.

Bank retreat study of a meandering river reach case study: River Irwell

R. Durán, L. Beevers, A. Crosato, N. Wright
Water Science and Engineering, UNESCO IHE, Westvest No7, 2611AX Delft, the Netherlands; rocdur@hotmail.com

Abstract
Lack of data is often considered a limitation when undertaking morphological studies. This research deals with the morphological study of a small river experiencing bank erosion for which only limited data are available. A reach of the meandering gravel-bed river Irwell (United Kingdom) is taken as a case study in order to analyze the bank retreat process that is endangering the stability of structures located in the area.

Two models of different complexity have been applied: A one-line meander migration model MIANDRAS and a 2D model built up using the Delft 3D software. The simple meander model produces satisfactory results in much less time using less data. The results show that the morphological development of the river may endanger the existing structures within the next five years, if no mitigation works are carried out.

Introduction
Free river meandering causes often a threat to existing structures along the river. To prevent problems, morphodynamic studies are useful. However, lack of data is often a limitation. The objective of this study is to determine a convenient type of modelling to assess future river migration trends of small meandering rivers with scarce available data. The study will be done by comparing two models of different complexity. For this purpose, a reach of the River Irwell, in the United Kingdom, is taken as a study case.

Material and Methods
The two models are built using: MIANDRAS (Crosato, 2008,1990) and Delft 3D (Lesser et al., 2004). The first one is a one-line meander migration model in which channel migration is related to the mean bank flow properties. The second is a 2D model in which bank erosion calculated with the dry-wet cell method (Van der Wegen et al. 2008). The models are first calibrated on the period 2003-2006 and thereafter, they are used to simulate the future river changes for the period 2006-2010.

Study area description
The study area is located east of Rawtenstall, Lancashire, United Kingdom. The River Irwell has its origin in the Irwell spring, 427 m above the mean sea level and the total area of the river basin contributing to the study reach is 120.7 Km². Channel migration is rather fast in the last years and may endanger the stability of existing structures: a weir, the A56 motorway bridge and a railway embankment. The main river characteristics are listed in Table 1.

Table 1. Main characteristics of the study reach

Length study reach (Km)	1.00
Channel width (m)	11.80
Bed slope (%)	0.53
Mean discharge in 2006 (m³/s)	3.50
Highest discharge (1996-2006) (m³/s)	53.00
Bankfull discharge (m³/s)	45.00
Mean sediment size D_{50} (mm)	11.20

Available data
A field survey was carried out in order to obtain more information about the river, such as the sediment characteristics. The topography data includes cross sections and LiDAR data, both of them property of The Environment Agency. A satellite image dated to June 2006 and a set of photographs of year 2007 are the only source of information of historic river planimetry. The main source of hydrological data is the Irwell Vale gauging station. A second source of information is an existing flow model.

Results
The models have been calibrated on the period 2003 to 2006. River alignment and bed topography computed with MIANDRAS are shown in Figure 1. The results are satisfactory because they match both bed topography, in terms of location of point bars and pools, and river alignment. Use of lower erodibility coefficients in areas with herbaceous vegetation and in the railway embankment contributed to better simulate the river behaviour.

The one-line meander model predicts well the magnitude and location of the bars present in the river except bars 8 and 9 (Fig. 1). MIANDRAS does not have the option to model weirs, therefore the effect caused by the weir upstream of the bridge is not considered in the results. The back water effect of the weir reduces flow velocity and sediment transport capacity so that sedimentation takes place. As a consequence of flow velocity reduction the bar number 5 is larger than model prediction and bar number 9 does not exist.

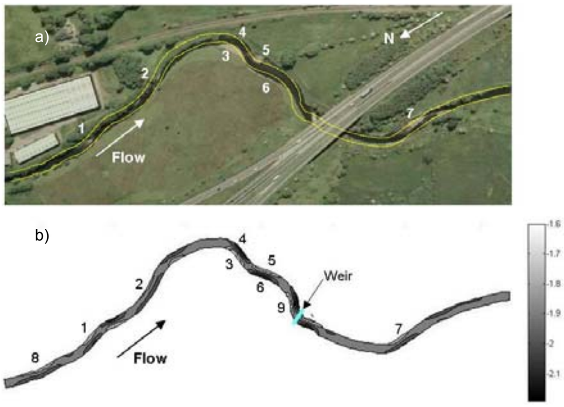


Figure 1. River characteristics in 2006 computed with MIANDRAS (a) River alignment (b) Bed topography.

River alignment and bed topography computed with Delft 3D are shown in Figure 2. The results show that the river becomes wider because the bank advance process is not taken into account and because the dry wet cell method promotes erosion even in straight reaches. The model assumes that the bank erodibility is uniform which may apply when the bank material is homogeneous, geotechnical properties are uniform and external loads and vegetation are the same along the river banks. However, these conditions are not the case of River Irwell. Therefore, uniform bank erodibility does not reproduce the river natural behaviour.

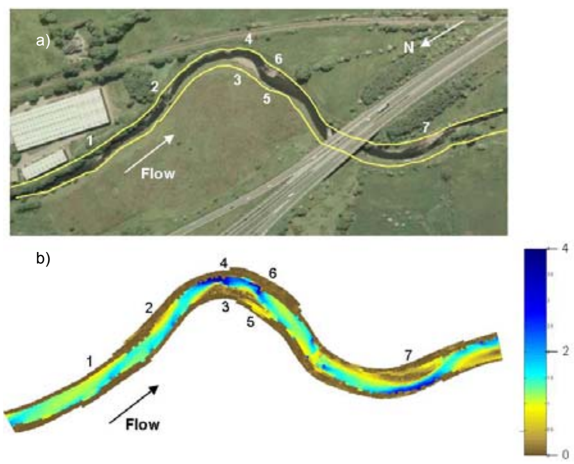


Figure 2. Characteristics in 2006 computed with Delft 3D (a) River banks alignment. (b) Bed topography.

The model reproduces well the reach downstream of the weir. However the results also show that point bar 3 is larger than the existing one. The erosion of the outer bank is overestimated in 4 which results in washing away bar 6. Additionally, the bank retreat process 5 that takes place downstream of the point bar 3 is not represented by the model and the existing pool is filled with sediment.

The future planimetric changes (Fig. 3) computed with MIANDRAS show that in 2010 the river starts to erode the area upstream and downstream of the weir. However, this is most probably overestimated. The model indicates that by year 2010 the left river bank might reach the railway embankment toe. The future planimetric changes computed with Delft 3D are characterized by non-realistic channel widening.

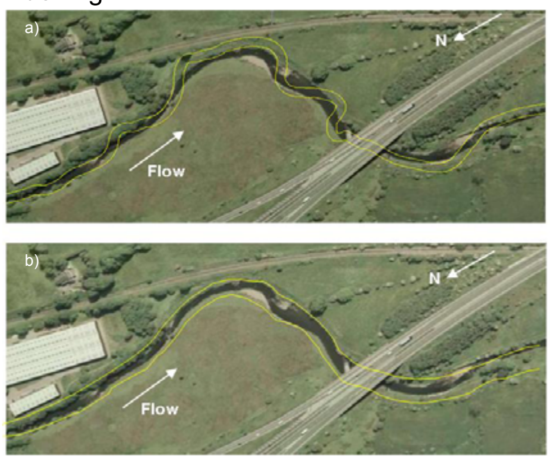


Figure 3. Irwell alignment prediction year 2010
a)MIANDRAS b)DELFT 3D

Conclusions

For the case of the River Irwell reach MIANDRAS appears the most suitable tool to compute the planimetric changes. Non-realistic widening obtained with Delft 3D model is due to the simplified bank erosion formulation and due to the lack of a bank accretion formulation. It is strongly recommended to include bank erosion and bank accretion in Delft 3D.

Acknowledgements

This study was carried out with the support of UNESCO-IHE institute for water education, the Dutch Fellowship Program and Edenvale Young.

References

Crosato, A. (2008). “Analysis and modelling of river meandering”. IOS Press. 251 p.

Lesser, G. R., J. A. Roelvink, J.A. van Kester and G. S. Stelling, (2004). "Development and validation of a three-dimensional morphological model", Coastal Engineering 51(8-9): 883-915.

Van der Wegen, M. Wang, Z.B. Savenije, H.H.G. J.A. Roelvink (2008). “Long-term morphodynamic evolution and energy dissipation in a coastal plain, tidal embayment”, J. Geophys. Res.

Bank stability of a tropical river in cohesive sediment

S.W. van Berkum[1*], B. Vermeulen[1] and A.J.F. Hoitink[1,2]
[1] *Hydrology and Water Management Group, Department of Environmental Sciences, Wageningen University, Droevendaalsesteeg 4, 6708 PB Wageningen, the Netherlands*
[2] *Institute for Marine and Atmospheric Research, Department of Physical Geography, Utrecht University, P.O. Box 80115, 3508 TC Utrecht, the Netherlands*
* *Corresponding author: sonja.vanberkum@wur.nl*

Abstract
The morphodynamics of rivers in clayey sediments have received comparatively little attention in the literature. The Kutai Basin (East Kalimantan, Indonesia) presents a lowland area where the River Mahakam meanders in cohesive sediment. The morphological processes and bank stability of the River Mahakam were analyzed by means of a stream reconnaissance according to Thorne (1998), sediment characterisation and borehole shear testing. The river banks were categorized into three main types. Large areas of the river are presently eroding, confirming the general belief that the river is widening. Aggrading cut-off channels in the Mahakam offer the possibility to study the process of channel closure under natural circumstances. Present efforts are focused on relating bank stability to the occurrence of metal concretions in the banks.

Introduction
The Kutai Basin is a subsiding low-land area on East-Kalimantan, Indonesia. In this extremely flat area, the central reach of the River Mahakam meanders in cohesive sediment. Fig. 1 shows that the river flows through its alluvium, which is confined by freshwater swamps and shallow lakes connected to the river by tie channels. The region experience a wet season with two flood periods during which water levels rise up to 6 m above dry season water levels. The lakes act as a buffer to river discharges, preventing peak discharges and low flows.

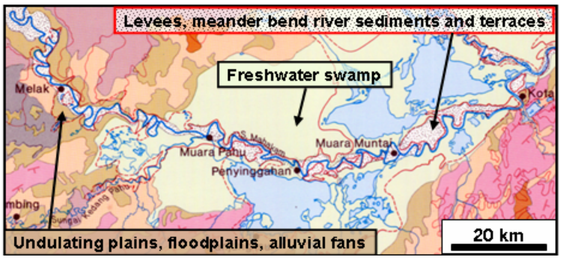


Figure 1. Geomorphological map of the research area

Deforestation is expected to result in larger discharge variation directly, by increasing runoff, and indirectly, by filling-up of the lakes with eroded sediment, diminishing the buffer capacity of the lakes. These developments are expected to cause changes in the morphodynamics of the river. The present research aims to establish and understand the dominating morphological processes in the central reaches of the River Mahakam.

Method
To describe and quantify the bank stability and the ongoing morphological processes of the River Mahakam, a stream reconnaissance following the methodology by Thorne (1998) was done during the dry season of 2008. Riparian vegetation, bank profile, bank material, and products of erosion and deposition were described at a large number of sites to characterize the river banks. Borehole shear tests were performed to provide information about the cohesion and internal friction angles of the sediment. Relating this with sediment characteristics will provide insight in the stability of the banks.

Preliminary Results
Based on the stream reconnaissance the river banks were categorized in three main types. Their characterization and occurrence is described below.

Bank types
The main characteristics of an erosive bank include little to no vegetation on the bank slope, mature vegetation on top of the bank, exposed roots, steep slopes, mass failures, and banks predominantly consisting of clay. This type of bank is found in outer bends, and on semi-straight sections with some curvature, as can be seen in Fig. 2. Erosive banks may also occur upstream of the inner bends, and within the inner bend of sharp bends.
Aggrading banks have a mild slope of 2° to 15°. Their vegetation is young and is located on the middle and upper bank, featuring roots that are covered or adventitious. Often, debris is found on aggrading banks and their height is lower than the erosive banks. A large part of aggrading banks consists of levees and behind these levees, floodplains can be found. The aggrading sediment is courser than material of

older, presently eroding banks, and predominantly consists of silt.
Stable banks have a dense vegetation coverage, normal roots, a large variety of plant types, an intermediate slope and only small signs of hydraulic erosion. These banks are typically found in straight sections of the river.

Point bars

Point bars in the River Mahakam usually consist of sand, silt and layers of leaves. In the downstream part of inner bends, point bars are often present. These seem to migrate downstream in the bend, as the upstream area of the point bar often shows clear marks of hydraulic erosion and the downstream section gradually transforms into an aggrading or stable riverbank.

Remarkably, some outer bends contain point bars, which are indicated by green arrows in Fig. 2. Their occurrence is related to erosion in the inner bend and in parts of the outer bend. This widening of the river causes the outer bend to become relatively inactive, leading to aggradation and the formation of an outer bend point bar.

Cut-offs

In Fig. 2 a cut-off channel is indicated by a black circle. The event creating the cut-off was about to take place in 1989 (Delft Hydraulics, 1989) when only 25 m was left between the upstream limb and downstream limb of the meander bend. Presently, the cut-off bend is still connected to the main channel, while it is slowly being filled with sediment. Only during very low water levels the channel becomes dry land.

A more complicated cut-off took place in 1912 / 1913, at an unknown moment. Ever since, the northern channel in the square indicated in Fig. 2 is aggrading.

Preliminary conclusions

From the observations it is concluded that the central reaches of the River Mahakam are morphologically highly active. Sharp bends feature aggradation in the outer bends and erosion in the inner bends. Point bars migrate downstream within an inner bend. The total length of eroding banks exceeds the length of aggradation, suggesting widening of the river. Furthermore, the River Mahakam features a clear example of side channel closure which offers the possibility to study aggradation in a natural setting.

Ongoing research

Presently, bore hole shear test are being analyzed to obtain cohesion and internal friction angles of several banks. In combination with a sediment characterization this will give insight in river bank stability, using existing theoretical bank stability models. In a subsequent stage, the possible influence of iron and manganese concretions on the bank stability will be investigated. A parallel study is focused on remote sensing images and aerial photographs of the Mahakam, aiming to reveal plan form changes of the river over two decades. Comparing the ongoing processes as described from the stream reconnaissance with the plan form developments over the last two decades may allow to detect shifts in morphological developments.

References

Delft Hydraulics (1989), Appendix 1 Mahakam river, IWT Kalimantan, Contribution Delft Hydraulics, Delft, the Netherlands.

Thorne, C.R. (1998), Stream Reconnaissance Handbook, John Wiley & Sons. 129p.

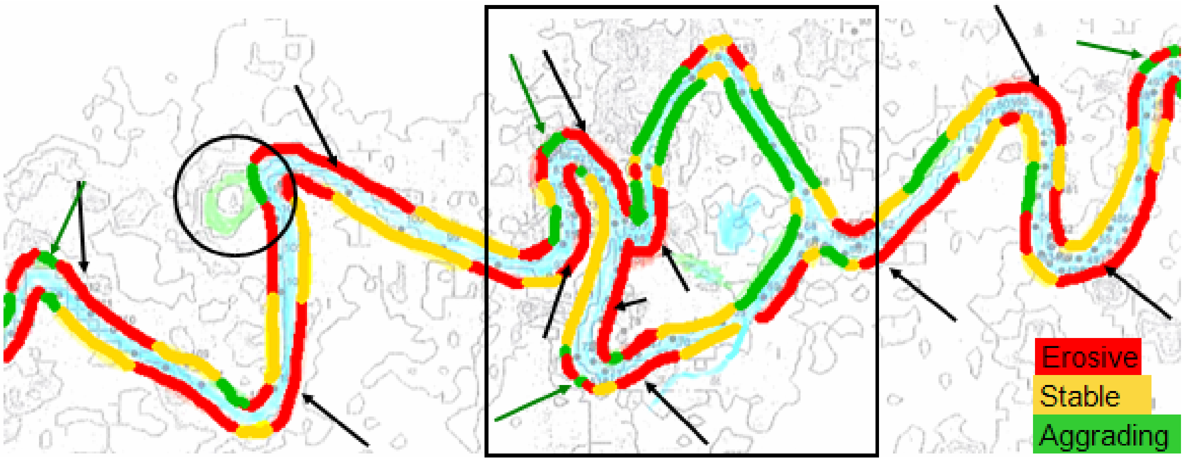


Figure 2. Bank characterisation of a river section at Muara Muntai

Computational Modelling of Bed Form Evolution Using Detailed Hydrodynamics: A Brief Review on Current Developments

S. Giri
River Engineering and Morphology, Deltares, Rotterdamseweg 185, 2629 HD Delft, the Netherlands; Sanjay.Giri@deltares.nl

Introduction

Prediction of micro-scale morphological behaviour of rivers and its influence on water surface variation is significantly associated with the local hydrodynamic and sediment transport characteristics as well as the flow resistance that is dominated by form drag exerted by bed forms like dunes. In order to replicate form drag exerted by bed forms in a physically-based manner, it is of importance to consider the detailed hydrodynamics. The problem turns out to be more complicated under varying flow condition. This requires an improved modelling approach that enables to take into account the variability of the bed form and the form drag under steady and varying flows. Within the scope of this report, we briefly describe current state of research regarding physically-based modelling of micro-scale bed form evolution using detailed hydrodynamics.

State-of-the-art in morphodynamic modelling of micro-scale bed forms

Morphodynamic numerical models have increased both in details and range of applicability, and being increasingly employed these days solving the sediment transport that depend on local and dynamic flow information. For this purpose, the local flow information is determined from high-resolution hydrodynamic models like DNS, LES or TRANS. At the same time, the sediment transport formulations that are incorporated in these models appear to be equally important.

Recently, Giri and Shimizu (2006) has proposed a morphodynamic model of bed form evolution. The model reproduces temporal development of river dunes and accurately replicates the physical properties associated with bed form evolution. Model results appear to provide accurate predictions of bed form geometry and form drag over bed forms for arbitrary steady and unsteady flows. The flow model component of the coupled morphodynamic model, which is two-dimensional in the stream wise and vertical directions, explicitly treats unsteadiness and non-hydrostatic effects. Non-equilibrium bed load sediment transport is treated using an Eulerian stochastic formulation of the sediment exchange process in terms of pick up and deposition functions proposed by Nakagawa and Tsujimoto (1980). The proposed approach for sediment transport explicitly considers the local flow variability during morphodynamic computation (A typical simulation result is depicted in Figure 1).

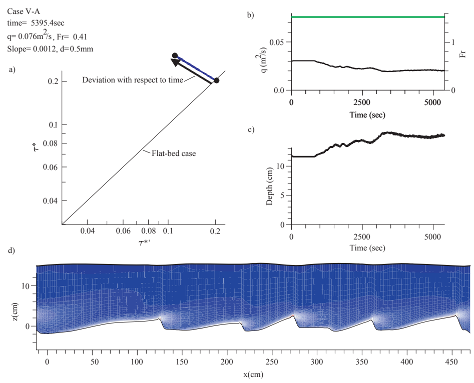


Figure 1. Simulation of bed form evolution and associated form drag, and flow-depth change (Giri & Shimizu, 2006)

Subsequently, this morphodynamic model has been extended (Giri et al., 2007) so that it can replicate the bed shear stress variation in accordance with the variation of form drag exerted by the temporal growth or decay of bed forms under temporally varying flows. The model is shown to reproduce dune evolution, transition to flat bed, and the reappearance of bed forms (Figure 2). In order to accurately simulate this phenomenon, an assumption was made in regard to the description of particle step-length parameter, used in the non-equilibrium sediment transport formulation. This parameter, which is usually treated as a linear function of particle size, is also varied as a function of boundary shear stress in the extended model. This more general formulation appears to produce better results for the treatment of bed form evolution in time varying flows, and is also consistent with most theoretical formulations of sediment motion. Furthermore, Yamaguchi and Shimizu (2008, unpublished) investigated the bed form evolution process incorporating Kovacs and Parker's sediment transport formula (1994) in the model, in which Ashida and Michiue's sediment transport formulation (1972) was modified by including the local bed slope effect.

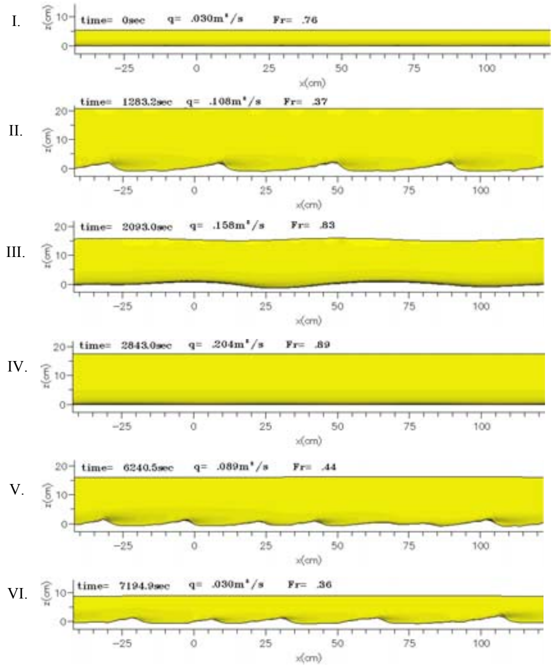


Figure 2. Numerical simulation of bed form evolution under varying flow (Giri et al., 2007)

From this investigation, it has been revealed that the perturbation grows rather rapidly without significant wavelength in case of Ashida and Michiue's formulation as it does not include slope effect (Figure 3). Whereas, in case of Kovacs and Parker's formula that includes local slope effect, the bed form appears to grow with larger wavelength. In this case, the bed forms with small scale disappear quickly apparently due to the effect of the local bed slope. Moreover, wavelength was found to be dependent on the bed slope coefficient.

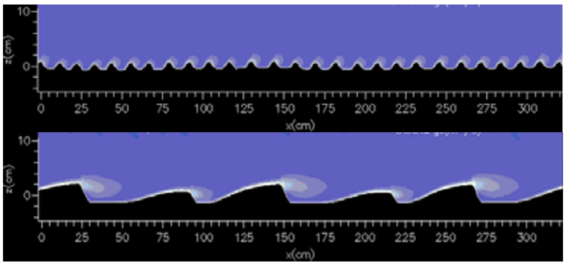


Figure 3. Instantaneous feature of bed forms simulated by using Ashida & Michiue's (top plot) and Kovacs & Parker's formulae (bottom plot)

Recent work of M. Nabi (2008, personal communication) on developing a three-dimensional LES model is also a significant step forward towards dealing with complex flow over complex boundaries. This hydrodynamic model comprises many advanced features like dynamic sub-grid scale model, and also multi-grid technique, which is rather useful approach to compute the flow and transport field with a local refinement of grids, and more efficient and reliable than the models with moving boundary coordinate system. The model incorporates a stochastic model of sediment transport with pick up and deposition as used in Giri and Shimizu (2006). Model appears to be able to reproduce pretty realistic feature of the three-dimensional bed forms (Figure 4).

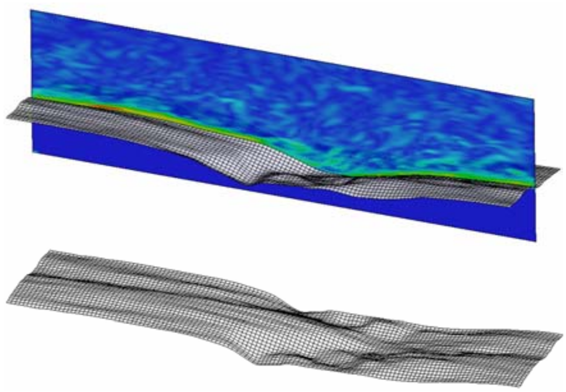


Figure 4. Three-dimensional feature of bed form and vorticity field (Courtesy of M. Nabi)

Concluding remarks

The advanced models that are capable to predict the bed form characteristics in a physically based manner still cannot be applied directly to address the real-world problems due to rather intensive computational efforts. Moreover, they still need further improvement. On the other hand, most morphological models with the real-world application consider only large scale and long-term morphological behaviour, and ignore the direct consideration of micro-scale bed form evolution and associated flow resistance (or consider it in a rather simplified manner). Consequently, the question how to harmonize the scientific advancement and engineering practice in an appropriate manner appears to be a challenging issue.

References

Abdu Nabi, M. (2008) Three-dimensional model of detailed hydrodynamics for simulation of subaqueous dunes, Proc. Mar. Sand. Riv. Dyn., MARID, Leeds, 235-240.

Ashida, K., Michiue, M. (1972) Study on hydraulic resistance and bedload transport rate in alluvial streams, Transactions of JSCE, 206, 59-69.

Giri, S., Shimizu, Y. (2006) Numerical computation of sand dune migration with free surface flow. Water Resour. Res. 42, W10422: doi:10.1029/2005WR004588.

Giri, S., Shimizu, Y., Yamaguchi, S., Nelson, J. (2007) Simulating temporal response of bedform characteristics to varying flows. Proc. of Int. Conf. on Riv. Coast. & Est. Morph., RCEM: 939-947.

Kovacs, A., Parker, G. (1994) A new vectorial bed load formulation and its application to the time evolution of straight river channels, J. Fluid Mech., 267, 153-183.

Nakagawa, H., Tsujimoto, T. (1980) Sand bed instability due to bedload motion, J. Hyd.Div., ASCE 106, 2029-2051.

Nelson, J. M., Shimizu, Y., Giri, S., Logan, B. L., Konzel, P. J., Shreve, R. L., McLean, S. R. (2008) Bedform response to flow variability, Proc. Mar. Sand. Riv. Dune Dyn., MARID, Leeds, 241-248.

Hydrological and morphological effects of stream restoration in Twente

R.C. Duijvestijn[1,2], C.M. Dohmen-Janssen[1], J.S. Ribberink[1], H.W. Grobbe[2]
[1] *University of Twente, Faculty of Civil Engineering, Postbus 217, Enschede; r.c.duijvestijn@student.utwente.nl*
[2] *Royal Haskoning, Colosseum 3, 7521 PV, Enschede*

Abstract
Due to canalization and implementation of weirs in river systems, water managers in the Netherlands were able to control the rivers. The current changes in river discharge however need new approaches. Changing rivers into more natural, dynamic water systems seems to be a possible answer. However, there is not much experience yet on how to realize this in practice. In this study the effects of removing weirs and implementing measures, such as small dams and meandering of the stream path, is being investigated. Removing weirs can only be done when other measures are taken in order to control the water flows, otherwise risks for flooding or drought become even larger. An important question is how 'natural' a river might be in the perspective of other constraints such as safety and agriculture. Most of the times a combination of measures is chosen in order to fulfil multiple goals.

Introduction
For centuries the Netherlands had the urge to control the water systems more and more. In order to discharge the water as quickly as possible, water systems were canalized and in order to maintain enough water during dry periods, weirs were constructed. Nowadays problems arise with more extreme discharge events. In winter the chance of extreme floods is growing as well as the chance of extreme droughts in the summer.
Due to national and European law and regulations, waterways have to be managed in new ways. Water quality has to be improved to improve ecological conditions and water has to be retained in the upstream parts of river basins to reduce droughts and floods. Smaller streams in the upstream part of a river system are often suitable for testing new management strategies.
Making waterways more natural is often the response to the new policy of making river systems more dynamic. The question that arises is: how natural does the stream need to be and how natural can it be? From the perspective of nature, a dynamic free flowing river may be the ultimate goal. On the other hand river flows need to be controlled, after all a large part of the Netherlands is still agricultural land and agricultural interests often conflict with the goals of a more natural environment.
This research tries to find answers to the question which measures can be taken best in order to realize natural streams that can fulfil the agricultural as well as nature conservation boundary conditions. The streams being investigated are located in Twente in the eastern part of the Netherlands, called the Saasvelderbeek and the Lemselerbeek.

The study investigates the hydrological and morphological effects of creating more natural streams. This includes the investigation of the effects of removing the presently existing weirs and implementing measures to i) reduce the flow velocity, and ii) keep the water level at a pre-determined higher level.

Situation
In the present situation the streams are eroded deep into the surrounding land. The combination of fine sand (75-150 μm) and large surface slopes (220 cm/km) requires many weirs to control the water flow in these streams.

Boundary conditions
Prior to the present research another study has been executed to determine the water levels of the stream in the future (see Figure 1). These water levels have been set in compliance with the policy of Preferred Ground- and Surface Water Regime (GGOR) (Kuks (2007)). This is set at a leading discharge of 1/4Q which will be reached at least 80 days a year. Other boundary conditions are determined according to the European Water Framework Directive and local policy.

Boundary conditions used are:
- Flow velocity (0.2 – 0.4 m/s)
- Determined water level (for 1/4Q)
- Total width of the corridor (15 m)

Approach
The responsible Water Board Regge & Dinkel is going to remove the weirs and will heighten the bed level. It is expected that as a result

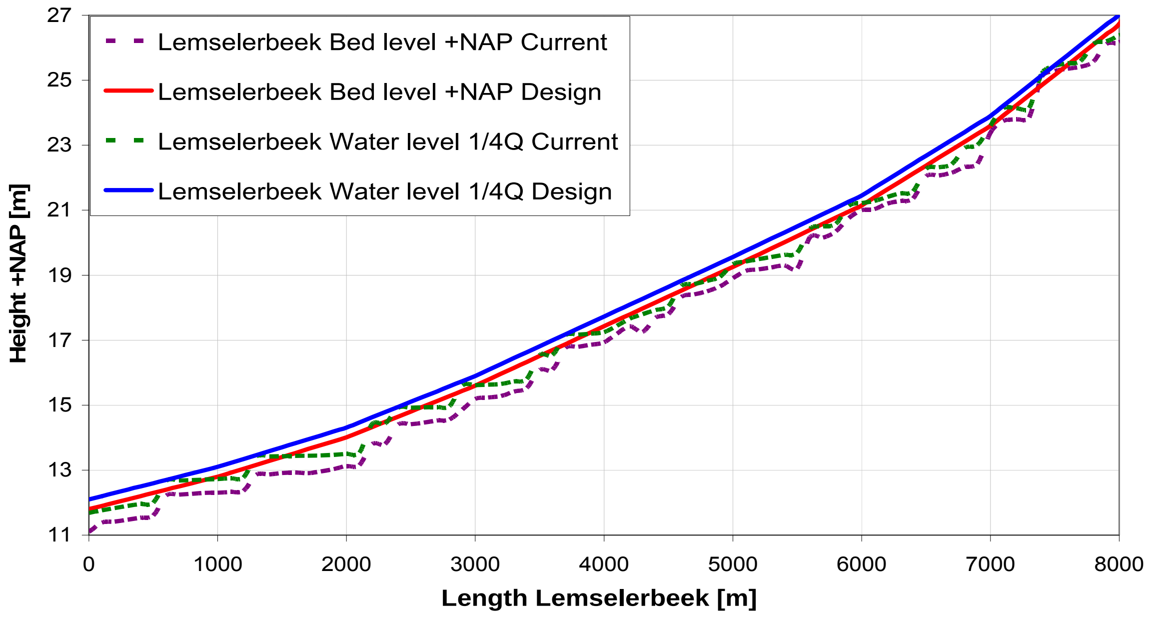


Figure 1. Longitudinal profile of stream (Scheer, J. van der (2006))

flow velocities will be (far) too high and the desired water levels will not be reached everywhere. Additional measures will have to be taken. In the present study two measures will be investigated i) a situation in which the total stream is filled with little dams (like cascades, stone dams and fish passages) and ii) one in which the stream is meandering. Since these streams were excavated a few centuries ago and always have been straight, the meander path has to be determined.

Model

The model used to investigate the results of implementing the measures is the one-dimensional program Sobek-RE. Small dams can be implemented in the model as well as increased stream lengths due to meandering. It should be realized that local effects of meandering, such as deposition in the inner bend and erosion in the outer bend cannot be made visible with Sobek. Another program is needed to do such research. The idea behind modelling in Sobek-RE is to investigate the hydraulic and morphological effects of the new longer stream path. It should also be realized that vegetation influences, which may alter the morphological stream evolution, are also not included in the present model.

Results

Although the investigation is not fully completed yet, it seems that in compliance with the boundary conditions it is possible to create a more natural stream. Meandering alone is in this case not the solution as the required length increase of the stream to create the desired water levels is too large and not realistic. Little dams alone can be a solution, but in fact the only thing done is to replace current weirs with a large number of small weirs. Furthermore, the natural look of this new stream can be discussed.
An alternative is a mixture of meandering and small dams. In the upper (steeper) part of the stream more small dams can be implemented together with a hardly changed stream path. In the lower part a more meandering path is feasible together with some little dams. Of course the dams can be created in such a way that they create variable flow velocities to induce a more dynamic river system.

Conclusion

Making streams and rivers more natural is a good idea and it fits well in the European and national law and regulations. However, it is necessary to understand the consequences of the choices that are made. The question ‘how natural or controllable does the river need to be’ needs to be answered. The effects of removing weirs are large and uncertain, therefore future monitoring of these streams is necessary to understand the effects better. Hopefully the outcomes of this research in combination with monitoring afterwards will give more insight in the behaviour of streams and perhaps it may contribute to the realization of more natural, dynamic rivers without weirs throughout the country.

References

Kuks, S.M.M. (2007). Actualisatie waterbeheersplan 2002-2005→2008. Water board Regge & Dinkel, Almelo, the Netherlands.

Van der Scheer, J. (2006). Memo maatregelen hydrologie. Water board Regge & Dinkel, Almelo, the Netherlands.

Coastal development during rapid SLR in the early-middle Holocene, western Netherlands

M.P. Hijma[1,2,3]

1 Utrecht Centre of Geosciences, Budapestlaan 4, 3584 CD Utrecht, the Netherlands, m.hijma@geo.uu.nl
2 Department of Physical Geography, Faculty of Geosciences, Utrecht University, P.O. Box 80.115, 3508 TC Utrecht, the Netherlands
3 Deltares, P.O. Box 85.467, 3508 TC Utrecht, the Netherlands

Abstract
Seismic data offshore The Hague reveal the presence of well preserved early-middle Holocene deposits below the seafloor. Analysis of the data shows how during a period of rapid sea-level rise (9-6 thousand years ago) the development of the fluvial and coastal systems was interlinked. It gives evidence for the infill of back-barrier channels as a result of a shift of the Rhine river mouth. It also indicates that ~6.7-6.5 thousand years ago the barrier system was overstepped, most likely as a result of a decrease of the gradient in the back-barrier basin.

Introduction
Today, satellites and tide gauges observe a global averaged rate of sea-level rise of 25-30 cm/century (Cazenave et al., in press). Many countries risk flooding of their coastal areas and study the geological record to understand the reaction of coastal systems to past periods of rapid sea-level rise and to predict future reactions of coastal areas to sea-level rise. This study is a contribution to that effort.
At the beginning of the Holocene, 12000 yr before present (BP), rates of sea-level rise were by far exceeding the present day rates due to rapid melting of the ice sheets of the last ice age. In the Netherlands, sea-level rose ~1 m/century at that time. After 8000 yr BP this rate started to slow down, but 6000 yr BP still was 30 cm/century (Jelgersma, 1961; Van de Plassche, 1982; Hijma and Cohen, in prep.). The development of the coastal system in the western Netherlands and the interaction between the coastal and fluvial systems during this period of rapid sea-level rise is the topic of this paper. It focuses on two questions:

1. How did the fluvial and coastal systems interact during the middle Holocene in the western Netherlands?, and
2. Did the coastline migrate continuously or stepwise?

Study area and methods
The study area is located offshore The Hague and is ~25 km long and ~10 km wide. Seismic data are the main source of information for this study. It was acquired using an X-star chirp-pulse system in a 1 km x 0.25 km grid. The seismic reflections were coupled to lithology using available core-descriptions. After the first analysis of the seismic data, four additional high quality cores were obtained for detailed information on the lithology at key locations. From these cores, also shells were collected for radiocarbon dating.

Results
Drowning of the southern North Sea allowed wave-action after ~8.5 kyr BP to build up embryonic barrier systems along a coastline west of the modern coast (Beets and Van der Spek, 2000). Behind that coastline, back-barrier basins flanked the Rhine-Meuse estuary near Rotterdam. After 8 kyr BP the Rhine mouth avulsed northward from the Rotterdam area to the Delft area (Hijma et al., subm.) and started to debouch in the studied back-barrier basin. Seismic data revealed back-barrier channels that started to fill in during this time. This was caused by increased fluvial sedimentation into the basins, resulting in a decrease of tidal prism and hence the back-barrier channels became too big in size. The resulting sand “hunger” of the back-barrier channels was stilled by marine erosion of offshore located sediments from the abandoned river mouth and Belgium-Zeeland headlands to the south. The eroded sediments were transported northward and alongshore into the back-barrier basins. Below the back-barrier deposits well preserved terrestrial deposits (inland aeolian dunes, peat and clay) were recognized.
Between 7.4 and 6.5 kyr cal BP the Rhine avulsed further north to the position of the ‘Oude Rijn’ which would be the main Rhine-branch until ~2 kyr BP (Berendsen and Stouthamer, 2000). The seismic data indicate that during that time the barrier-system was overstepped to a position near the present coastline. The evidence for barrier overstepping rather than gradual inland migration is indirect (following Rieu et al., 2005). Would the barrier-system have retreated continuously, scour features of tidal inlet channels should dissect back-barrier deposits. The lack of any of such features in the seismic data in a 50-km wide zone parallel to the modern coast favours stepwise retreat.

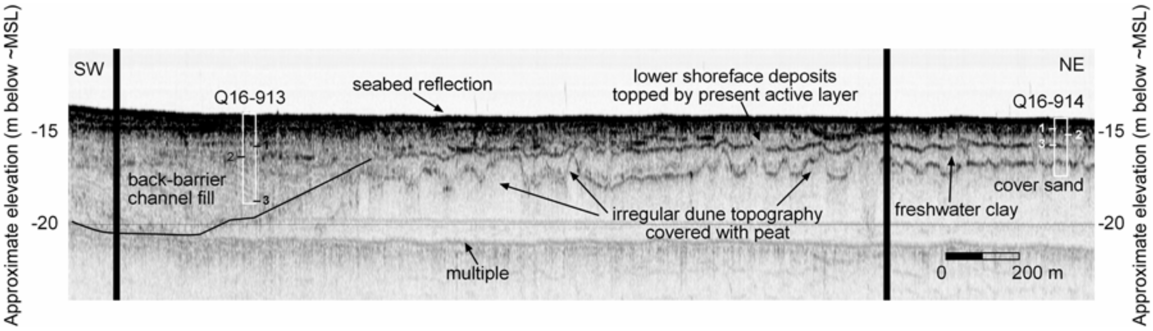


Fig. 1. Seismic cross-section showing a back-barrier channel fill besides well preserved terrestrial deposits.

Also, the back-barrier channels show very little lateral migration, indicating that they have been active for a relatively short time. This observation can be explained by barrier overstepping.
Overstepping was probably stimulated by the fore mentioned increased sedimentation into the back-barrier basins. The resulting decrease in gradient caused the basin to widen quickly as sea-level rise was still rapid. This can lead to overstepping (Swift, 1968; Rampino and Sanders, 1980).

Conclusion

This study shows that early-middle Holocene fluvial, marine and terrestrial deposits have been well preserved below the present seafloor. This allowed answering the two questions of this paper:

1. There is a clear interlinked development of the fluvial and coastal system. The shift of Rhine-mouth resulted in a decrease of tidal prism in the studied basin that led to the infill of the back-barrier basin.
2. Coastline retreat was characterised by at least one period of barrier overstepping around ~6.7-6.5 kyr BP. This was induced by a decrease of the back-barrier gradient due to either fluvial sedimentation or a decrease of the gradient of the Pleistocene substrate.

References

Beets, D.J. & Van der Spek, A.J.F., 2000. The Holocene evolution of the barrier and the back-barrier basins of the Belgium and the Netherlands as a function of late Weichselian morphology, relative sea-level rise and sediment supply. Netherlands Journal of Geosciences - Geologie en Mijnbouw 79: 3-16.

Berendsen, H.J.A. & Stouthamer, E., 2000. Late Weichselian and Holocene palaeogeography of the Rhine-Meuse delta, the Netherlands. Palaeogeography, Palaeoclimatology, Palaeoecology 161 (3-4): 311-335.

Cazenave, A., Lombard, A. & Llovel, W., Present-day sea level rise: A synthesis. Comptes Rendus Geosciences In Press, Corrected Proof.

Hijma, M.P. & Cohen, K.M., in prep. Early Holocene groundwater- and sea-level rise at the Rhine-Meuse mouth (Rotterdam, the Netherlands).

Hijma, M.P., Cohen, K.M., Hoffmann, G., Van der Spek, A.J.F. & Stouthamer, E., subm. From river valley to estuary: early to middle Holocene evolution of the lower Rhine-Meuse delta, the Netherlands. Netherlands Journal of Geosciences - Geologie en Mijnbouw.

Jelgersma, S., 1961. Holocene sea-level changes in the Netherlands. Mededelingen Geologische Stichting, 7: 101 pp.

Rampino, M.R. & Sanders, J.E., 1980. Holocene transgression in South-central Long Island, New York. Journal of Sedimentary Petrology 50 (4): 1063-1079.

Rieu, R., van Heteren, S., van der Spek, A.J.F. & De Boer, P.L., 2005. Development and Preservation of a Mid-Holocene Tidal-Channel Network Offshore the Western Netherlands. Journal of Sedimentary Research 75 (3): 409-419.

Swift, D.J.P., 1968. Coastal erosion and transgressive stratigraphy. Journal of geology 126: 235-248.

Van de Plassche, O., 1982. Sea-level change and water-level movements in the Netherlands during the Holocene, Vrije Universiteit (Amsterdam): 93 pp.

Reconstruction of sedimentation rates in embanked floodplains, a comparison of four methods

N. Hobo[1,2], B. Makaske[1], H. Middelkoop[2], J. Wallinga[3]
[1] *Alterra, Wageningen University & Research Centre; noortje.hobo@wur.nl*
[2] *Department of Physical Geography, Faculty of Geosciences, Utrecht University*
[3] *Netherlands Centre for Luminescence dating, TU Delft*

Abstract
Reconstruction of over bank sedimentation rates over the past decades to centuries can give insight into future floodplain dynamics, and provide a basis for efficient and sustainable floodplain management. We compared the results of four independent reconstruction methods, and investigated their optimal temporal and spatial range of application. These ranges differ by method, but show significant overlap. Results from a cross-section at Neerijnen show that dating results are generally in agreement, although some discrepancies deserve further attention.

Introduction
Planned landscaping measures in the embanked floodplains along Rhine branches in the Netherlands aim at enhancing the discharge capacity and restoring nature values, and include mining of clay, sand and gravel. An efficient and sustainable floodplain management strategy requires insight into the sedimentary dynamics of floodplains. One essential aspect is reconstruction of sedimentation rates during the past decades to centuries.
Goal of our research is to reconstruct the sedimentation rates since river normalization around 1850 AD in embanked floodplains, using four independent dating methods. Results will provide a basis for modeling future sedimentary dynamics. The model results can be used to set up guidelines for floodplain management that maintains the discharge capacity of the embanked floodplains, while also giving room to vegetation succession.

Dating methods
We use four methods to reconstruct over bank sedimentation rates. Below, the principles of these methods are described.

Flood bed interpretation
Flood bed interpretation involves correlation of individual layers in a vertical soil profile to peak events in the flood record (Fig. 1). This method allows for estimating the age of deposition of a single layer, but the uncertainty range increases with increasing age of sediments.

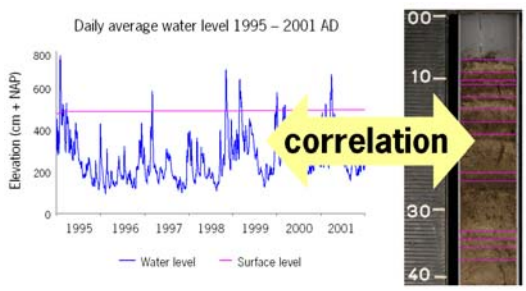


Figure 1. Flood bed interpretation involves correlation of peak events to individual layers in the soil.

^{137}Cs-dating
The unstable isotope ^{137}Cs enters the floodplain by atmospheric fallout and by deposition of suspended sediment to which it is bound. Peak years of deposition were 1960 (nuclear bomb tests) and 1986 (Chernobyl accident). When these peaks can be identified in a vertical soil profile, sedimentation rates can be calculated (Rigollet & De Meijer, 2002).

Heavy metal analysis
Since approximately 1860 AD, urban and industrial activities led to a significant increase in the heavy metal concentration of the Rhine water. In water, heavy metals are bound to the fine suspended sediment particles, and enter the floodplain during floods. Comparison of heavy metal contents in a vertical soil profile with the known pollution history enables calculation of sedimentation rates (Middelkoop, 2000).

OSL dating
Sand-sized quartz grains that are deposited on a floodplain become buried and shielded from sunlight. Due to exposure to natural ionizing radiation, charge is trapped inside the quartz crystal. This charge gives rise to an OSL signal that provides a measure for burial time. Application of OSL dating to young fluvial deposits is challenging because limited light exposure of the grains during fluvial transport may cause age overestimation.

Spatial and temporal range
All methods have a different spatial and temporal range in which they are best applicable (Fig. 2). Flood bed interpretation is only applicable close to the river, where individual flood beds can be recognized. The uncertainty range increases with increasing age of sediments. Cesium dating yields best results on the levee and proximal parts, where sedimentation rates are sufficient to distinguish between the peaks of 1960 and 1986 AD.

Heavy metal analysis is best applicable in the distal parts, where fine grained sediments to which heavy metals are bound are deposited. Finally, OSL-dating is used in sandy levee deposits and can date sediments well beyond the century scale, but for our young deposits the method is challenging.

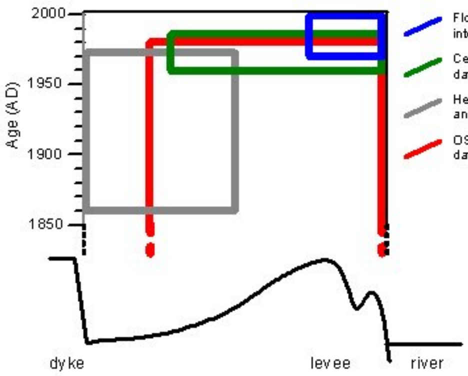


Figure 2. Optimal spatial and temporal range of applied methods.

Comparison

In both the temporal and spatial range there is overlap in applicability of the methods. We compared results within this overlap at a sand bar, a levee, and a distal site in the Neerijnen floodplain (Fig. 3). We used ^{137}Cs-dating results of Maas et al. (2003). All other methods were applied in our study. Flood bed interpretation yields similar sedimentation rates as ^{137}Cs-dating, but sedimentation rates resulting from OSL dating are slightly lower. Heavy metal analysis leads more or less to the same results as ^{137}Cs- and OSL dating (Fig. 4).

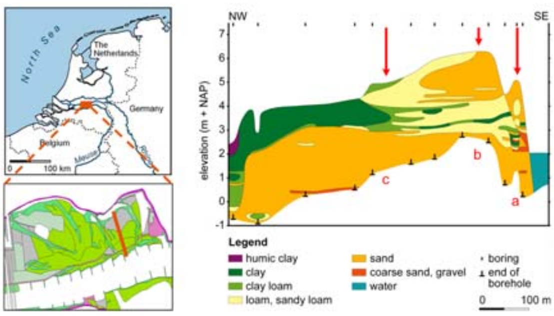


Figure 3. Cross-section at Neerijnen, with the sand bar (a), the levee (b), and the distal site (c) used for sampling.

Conclusions

There is a considerable and measurable amount of sedimentation on the floodplains, which is important to take into account in floodplain management. Within the spatial and temporal overlap, dating results are generally in agreement. Some small discrepancies exist, particularly for the sedimentation rates in the sand bar. Next step in our research is to focus on these discrepancies, and to determine the combination of methods that will yield most accurate sedimentation rates at a decadal to century time scale.

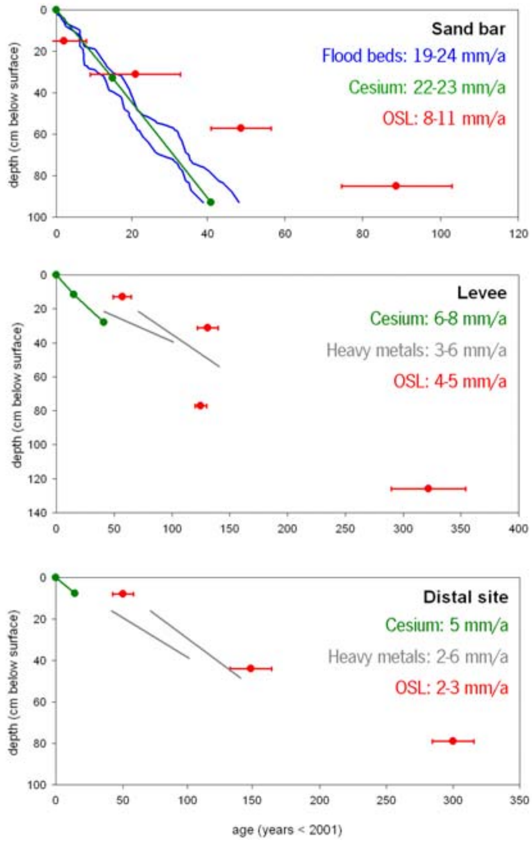


Figure 4. Sedimentation rates for different methods.

Acknowledgements

This research is part of the strategic research program “Sustainable spatial development of ecosystems, landscapes, seas and regions" which is funded by the Dutch Ministry of Agriculture, Nature Conservation and Food Quality, and carried out by Wageningen University and Research centre. OSL dating of flood deposits is supported by NWO/STW.

References

Maas, G.J., B. Makaske, P.W.F.M. Hommel, B.S.J. Nijhof, H.P. Wolfert (2003) Verstoring en successie; Rivierdynamiek en stroomdalvegetaties in de uiterwaarden van de Rijntakken. Alterra, Alterra-rapport 759. Wageningen, the Netherlands.

Middelkoop, H. (2000) Heavy-metal pollution of the river Rhine and Meuse floodplains in the Netherlands. Netherlands Journal of Geosciences, 79 (4): 411-428.

Rigollet, C., R.J. de Meijer (2002) PHAROS: A pluri-detector, high-resolution, analyser of radiometric properties of soil. Nuclear Instruments and Methods in Physics Research, 488: 642-653.

Clastic lake fills in the Angstel-Vecht area

I.J. Bos[1,2] and H.J.T. Weerts[2,3]

[1] *Utrecht University, Faculty of Geosciences, Department of Physical Geography. P.O. Box 80.115, 3508 TC, Utrecht, the Netherlands; I.Bos@geo.uu.nl;*

[2] *TNO, Geological Survey of the Netherlands, P.O. Box 80.015, 3508 TA Utrecht, the Netherlands.*

[3] *RACM, Postbus 1600, 3800 BP Amersfoort, the Netherlands.*

Abstract

Clastic lake fills are over bank deposits and form on deltaic plains when a fluvial distributary debouches into a lake. Based on field data, we describe the architecture and facies distribution of clastic lake fills in the Rhine-Meuse delta. We found these deposits on average comprise 30% sandy facies, which contrasts to other overbank deposits. We conclude that this affects the geomechanical, hydrological and reservoir properties of fluvio-deltaic successions.

Introduction and study area

Lakes occur in distal zones of deltaic plains. They form in peat areas where fluvial activity is absent and in distal parts of the delta where base-level rise leads to sediments deficits. These lakes may fill in with organics or with clastic deposits when a river occupies the area. In the Rhine-Meuse delta so-called clastic lake fills have been reported but never described in detail. This hampers e.g. the assessment of hydrological and geomechanical properties of the deposits. The aim of this study is to identify the architecture and facies distribution of clastic lake fills in the Rhine-Meuse delta. Two study areas were selected: 1) the central delta where clastic lake fills are present in the basal part of the Holocene succession and 2) the Angstel-Vecht area (Fig. 1). Part of the results from the Angstel-Vecht area is presented here.

Methods

In the Angstel-Vecht area clastic lake fills are present near the surface. This enabled detailed analyses of the facies distribution of the clastic lake fills. Based on a high resolution DEM and corings a geomorphogenetic map and cross sections were constructed. From these the architecture and facies distribution were determined. Facies interpretations were based on sedimentary, pollen and diatom analyses. Diatom and pollen analyses were carried out on 44 samples distributed over two high-quality mechanical piston cores.

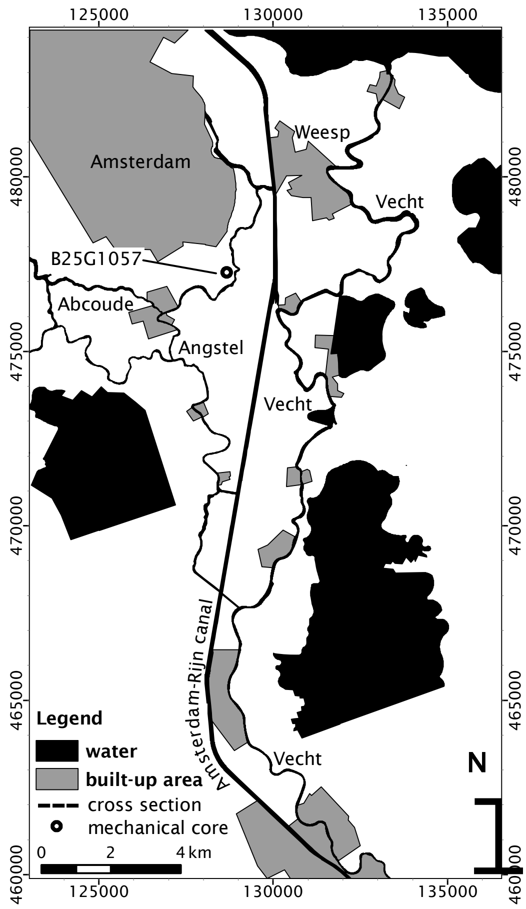
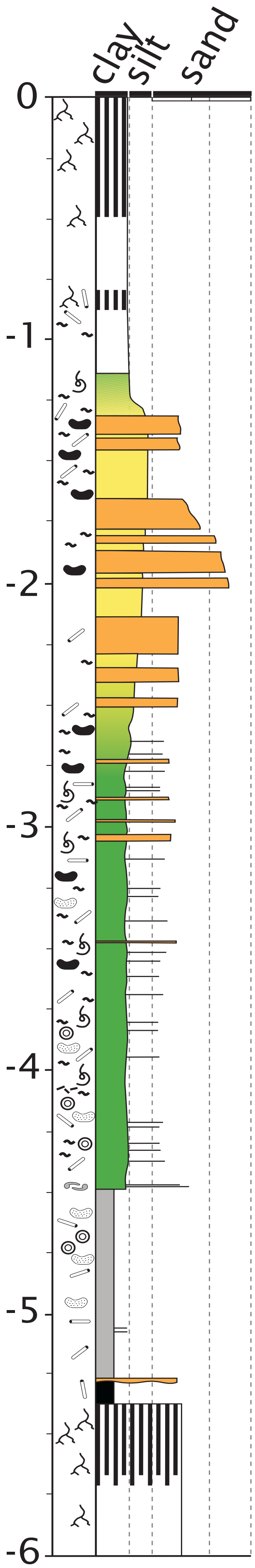
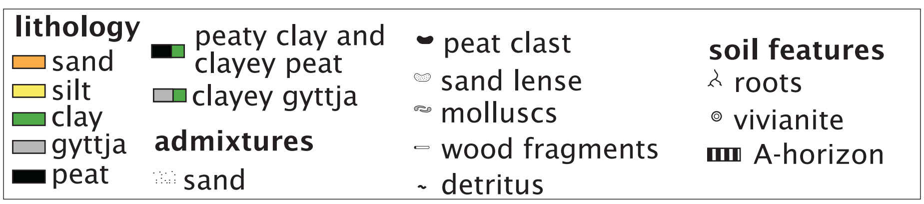


Figure 1. Topographic map of the Angstel-Vecht area. Indicated is the location of the sedimentary log (Fig. 2).





Results

The area of the investigated clastic lake fills is up to 30 km^2, the thickness is 3 - 5 m (Fig. 2). The transition to the surrounding peat areas is generally sharp and marked. The deposits comprise a clastic layer that includes a coarsening-upward sequence overlying organic lake sediments (gyttja).
The sedimentary logs (Fig. 2) show the laminated character of the deposits, indicative for lacustrine deposition. The diatom and pollen analyses clearly indicate deposition in a standing fresh water body of which the depth decreases upward in the sequence.
Comparable results are found in other investigated areas in the Rhine-Meuse delta.

Conclusions and further research

Lakes act as sediment traps. Therefore, the sediment characteristics of the fluvial system are reflected in the composition of clastic lake fills.
Clastic lake fills can be recognized as separate architectural elements in distal zones of fluvio-deltaic successions because of distinct geometrical and facies properties. They are potential ground water and hydrocarbon reservoirs. Clastic lake fills are associated with peat areas in delta plains and are prominent at the base of fluvial successions. They often include significant portions of sand, in the Angstel-Vecht area > 25 %. This greatly affects the hydrological and geomechanical properties which are important for reservoir characteristics.

Figure 2. Sedimentary log of a coring near Abcoude (the location is indicated in Fig. 1).
Note the coarsening-upward succession in the clastic lake fill and the frequent occurrence of peat clasts.

Advances in optical dating of young fluvial deposits

J. Wallinga[1], A.C. Cunningham[1], N. Hobo[1,2,3], B. Makaske[2], H. Middelkoop[3], D. Maljers[4], M.A.J. Bakker[4]

[1] *Netherlands Centre for Luminescence dating, Delft University of Technology, j.wallinga@tudelft.nl*
[2] *Alterra, Wageningen University & Research Centre; noortje.hobo@wur.nl*
[3] *Department of Physical Geography, Faculty of Geosciences, Utrecht University*
[4] *Deltares, Utrecht*

Abstract
Optically stimulated luminescence (OSL or optical) dating can be used to determine the time of deposition of sediments. Application of the method for young fluvial deposits is difficult due to incomplete zeroing of the luminescence clock, resulting in overestimation of the burial age. Here we present new optical dating methods and ages obtained on two sites in embanked floodplains of the River Waal. Results are in correct stratigraphical order and agree favourably with available age constraints.

Introduction
Fluvial deposits provide an archive of the behaviour of rivers in the past. This natural archive can be exploited to improve our understanding of fluvial systems and thereby aid the development of safe and sustainable river management strategies. Reliable dating methods are essential to read the geological archive. Available dating methods are, however, largely restricted to fine-grained deposits.

Aim
In this study we explore the applicability of Optically Stimulated Luminescence (OSL or optical) dating for determining the time of deposition of fluvial sediments in embanked floodplains. We present the first results of our investigations, obtained using optimised single-aliquot optical dating methods. We investigated both overbank and channel facies formed during the past decades to centuries.

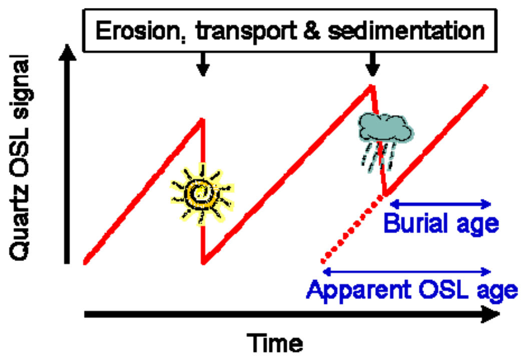


Fig. 1. The resetting of the OSL signal.

Methods
Optical dating determines the last exposure to light of sand-sized grains of quartz. If light exposure prior to deposition and burial is limited, the OSL signal may not be completely reset, resulting in overestimation of the burial age, especially for young samples (Fig. 1). To avoid OSL age overestimation we developed optical dating methods that are particularly suited for young fluvial deposits, most important advances are shown in Figs. 2 – 4.

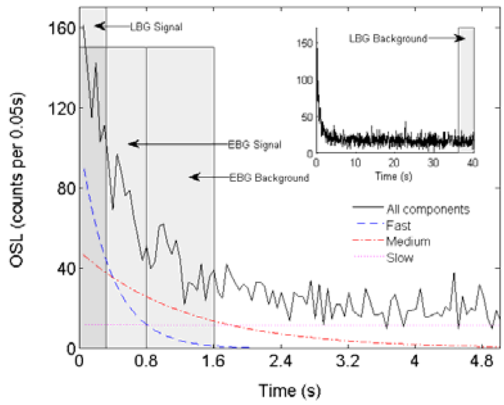


Fig. 2. The quartz OSL signal is composed of different components. The fast component is most suitable for dating and is selected through early background (EBG) methods.

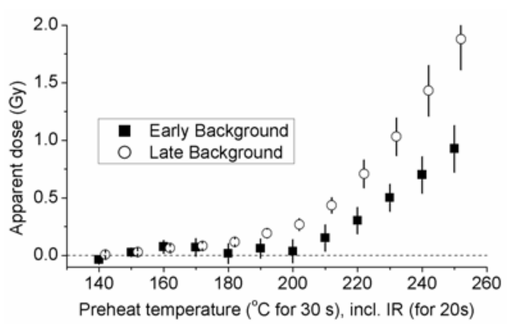


Fig. 3. Heating the samples prior to OSL measurement is needed to compare the natural OSL signal to that induced by laboratory irradiation. However, stringent preheating should be avoided as it may induce charge transfer from less light-sensitive traps (rising trend shown above). To avoid age overestimation due to charge transfer we selected a preheat of 200° C for these young samples.

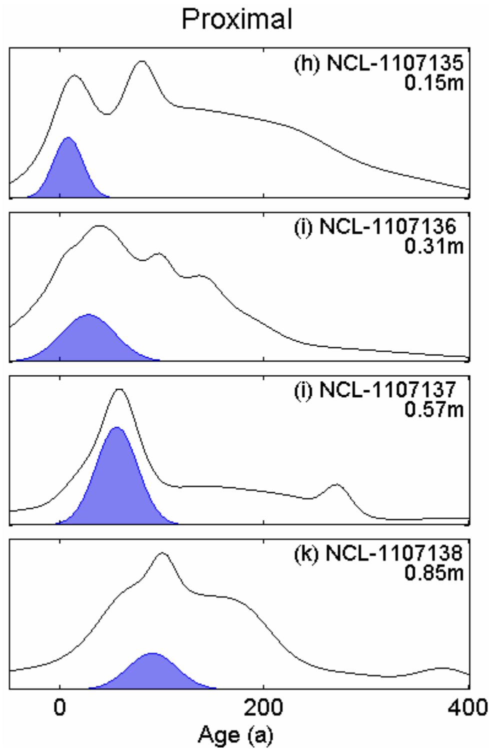


Fig. 4. OSL measurements are made on many small sub samples. The tail of the distribution toward older ages is caused by incomplete resetting of the OSL signal in some grains. Hence, youngest results will reflect the burial age. We distilled the burial age by fitting a Gaussian to the youngest part of the age distribution. The age distributions for four samples from a core on the Waal river bank at Neerijnen are shown.

Results

The optical dating results obtained are in correct stratigraphical order and agree with independent age constraints. The data can be used to determine sedimentation rates in the Neerijnen (Fig. 5) and Winssen (Fig. 6) floodplains. Our results demonstrate the applicability of optical dating for dating fluvial deposits on decadal to century timescales.

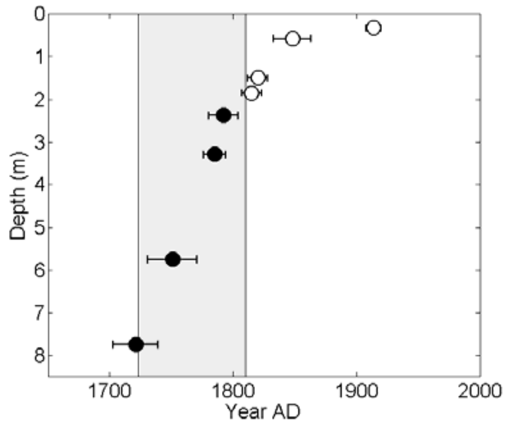


Fig. 6. Optical dating results for 8 samples from embanked floodplain sediments of the Waal near Winssen (Bakker et al., 2007; Cunningham et al., submitted). Results indicate rapid sedimentation of channel sediments, followed by slower aggradation of overbank deposits.

Acknowledgements

JW and ACC are supported by NWO/STW grant DSF.7553. This research contributes to the strategic research program "Sustainable spatial development of ecosystems, landscapes, seas and regions" which is funded by the Dutch Ministry of Agriculture, Nature Conservation and Food Quality, and carried out by Wageningen University Research centre.

References

Bakker, M.A.J., Maljers, D., Weerts, H.J.T., 2007. Ground-penetrating radar profiling on embanked floodplains. Netherlands Journal of Geosciences - Geologie en Mijnbouw 86, 55-61.

Cunningham, A.C., Wallinga, J., Maljers, D., Bakker, M.A.J. OSL dating of young fluvial quartz using early background subtraction. Quaternary Geochronology – submitted.

Hobo, N., Makaske, B., Middelkoop, H., Wallinga, J. This issue. Reconstruction of sedimentation rates in embanked floodplains, a comparison of four methods. NCR proceedings 2008.

Wallinga, J., Hobo, N., Cunningham, A.C., Versendaal, A.J., Makaske, B., Middelkoop, H. Sedimentation rates on embanked floodplains determined through quartz optical dating. Quaternary Geochronology – submitted.

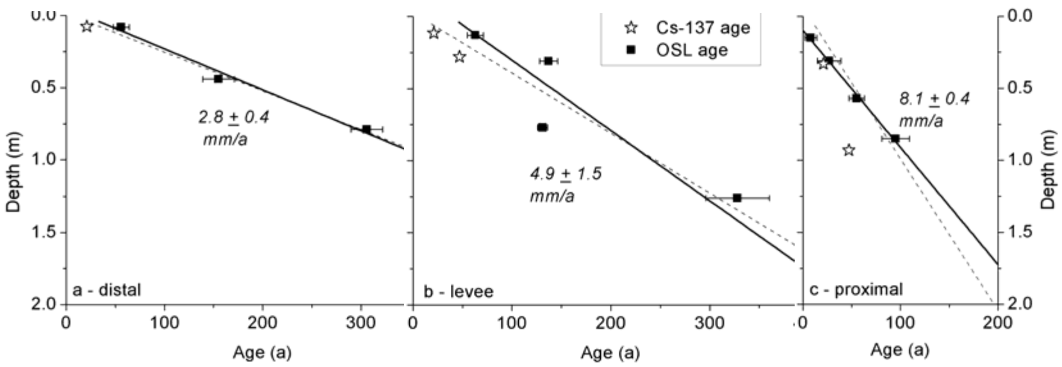


Fig. 5. Optical dating results and derived sedimentation rates for embanked floodplain overbank deposits of the Waal near Neerijnen (see also Hobo et al., this issue; Wallinga et al., submitted).

winner of the NCR-days poster Award 2008

Landscape change and biodiversity values of floodplains along the River Vistula, Poland

M. Wozniak[1,2], R.S.E.W. Leuven[3], H.J.R Lenders[3], T.J. Chmielewski[4], G.W. Geerling[2], A.J.M. Smits[2]

1 Department of Landscape Architecture, The John Paul II Catholic University of Lublin, Konstantynow Street 1H, 20-708 Lublin, Poland
2 Institute for Science, Innovation and Society, Radboud University, P.O Box 9010, 6500 GL Nijmegen, the Netherlands, m.wozniak@science.ru.nl
3 Department of Environmental Science, Institute for Wetland and Water Research, Radboud University, P.O Box 9010, 6500 GL Nijmegen, the Netherlands
4 Department of Landscape Ecology and Nature Conservation, University of Life Sciences, Dobrzańskiego St 37, 20-262 Lublin, Poland

Abstract
This paper deals with the effects of landscape change on spatial distribution of ecotopes and the assessment of biodiversity values of the Middle Vistula river valley in the Kazimierski Landscape Park (Poland), using the BIO-SAFEv model. The actual biodiversity values of the river valley in are high in comparison with floodplains of other lowland rivers in Europe. GIS-analyses of remotely sensed ecotope maps show remarkable differences in number, acreage and patchiness of ecotopes for the years 1953 and 2003. Side channels and floodplain lakes became fragmented. The average and total surface area of bush, forest and arable land increased, but decreased for bare soil, pioneer vegetation and grassland. These changes in distribution of ecotopes indicate both natural vegetation succession and increase of human impacts (e.g., intensification of agriculture and progressive impacts of river regulation). Current landscape changes negatively affect biodiversity values.

Introduction
In spite of floodplain embankment for urbanisation, industrialisation and agriculture, the Middle Vistula River still shows rather natural hydro-morphological characteristics with sandy islands, braided-meandering channels and species rich vegetation (Kajak, 1993). Therefore, the Vistula River is often used as reference for other lowland rivers. This paper describes the impact of landscape changes on distribution of ecotopes and biodiversity values of the Middle Vistula river valley (Fig. 1). It aims to answer the following research questions:

1. What are the changes in the number, surface area and patch size of ecotopes over the period 1953-2003?
2. What are actual biodiversity values in comparison with floodplains along the rivers Rhine and Meuse?

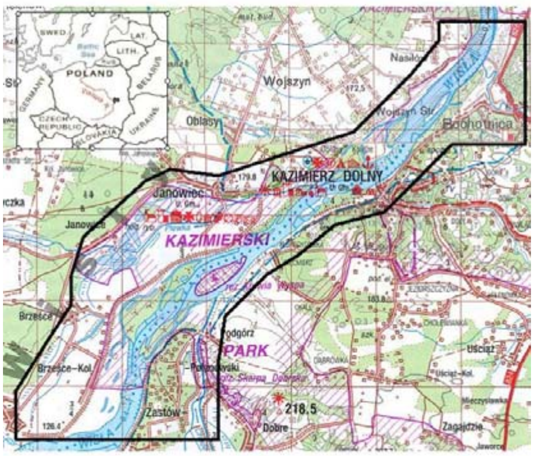


Figure 1. Location of the study area.

Study area
The River Vistula is the largest river in Poland, crossing the whole country from the Carpathian Mountains in the south to the Baltic Sea in the north (Fig. 1). Our study areas are located in the Middle Vistula river valley. The subsoil of the river valley mostly consists of course-grained sandy-clay soils. Owing to historical data availability, two sites in the Kazimierski Landscape Park (Lubelski Province) were selected for our case studies:

1. The river valley between the villages Janowiec and Nasiłow (rkm 357-363; 482 ha) for assessment of actual biodiversity values; and
2. The river valley between the villages Lucimia and Kazimierz Dolny (rkm 249-359; 1107 ha) for analysing effects of landscape change on biodiversity values.

Methods
Actual biodiversity values are quantified using the Taxonomic Biodiversity Saturation (TBS) index in the Vistula version of BIO-SAFEv (Wozniak et al., 2009), a model meant to quantify biodiversity and to value ecotopes based on legally protected species (Lenders et al., 2001; De Nooij et al., 2004).
Biodiversity values were calculated using the actual distribution data of legally protected flora and fauna species. These data were obtained from several atlases and regional surveys. Landscape change was analysed using a retrospective method (Geerling et al., 2006). Ecotope maps were digitized using black- and white aerial photographs of the

years 1953 and 2003 with stereoscopic verification. The maps were validated by ground truth and comparisons with topographical maps. The number, acreage and patchiness of ecotopes were analysed using ArcGIS 9.0.

Results

- The study area shows remarkable landscape changes over the period 1953-2003 (Fig. 2). The total number of ecotope patches increased with 43.8 %. Side channels and floodplain lakes became fragmented. The average and total surface area of bush, forest and arable land increased, while that of natural pioneer vegetation and grassland decreased.
- In comparison with floodplains along lowland reaches of the rivers Rhine and Meuse, the Vistula river valley still represents high biodiversity values for higher plants, mammals, fish and herpetofauna (Fig. 3).

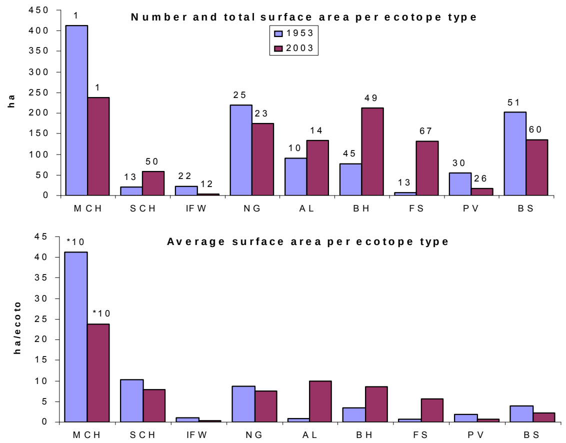


Figure 2. Changes in ecotope numbers, total surface area and average patch size (1953-2003). MCH: main channel; SCH: side channel; IFW: isolated floodplain water; NG: natural grassland; AL: arable land; BH: bush; FS: forest; PV: pioneer vegetation; BS: bare soil.

Discussion

The ecotope changes indicate both natural vegetation succession and increase in anthropogenic impact (intensification of agricultural land use and progressive river regulation by construction of embankments and groynes (Wozniak et al. 2009). In spite of several anthropogenic impacts, the Middle Vistula river valley still represents high biodiversity values. Many nationally and internationally protected species were recorded in recent field surveys. However, extensive analyses of recent landscape change with BIO-SAFEv show a decline of the potential values of the Middle Vistula river valley for several groups of protected and endangered species (Wozniak et al. 2009). Assessments with policy-based valuation models for biodiversity and ecotopes, such as BIO-SAFEv, can help to balance biodiversity conservation, river management and landscape planning.

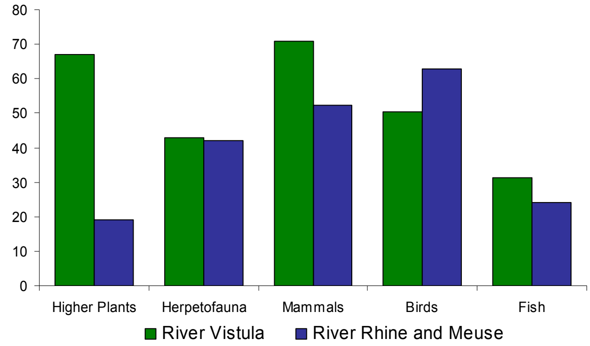


Figure 3. Taxonomic Biodiversity Saturation indices per taxonomic group in Poland and in the Netherlands (TBS, 0-100).

Conclusions

- The actual biodiversity values of the river valley in Kazimierski Landscape Park are high in comparison with floodplains of other lowland rivers in Europe (Rivers Rhine and Meuse).
- The landscape changes indicate both natural vegetation succession and increase in anthropogenic impact.
- The changes in riverine ecotope distribution are expected to affect biodiversity values of the river valley in the near future.

References

De Nooij, R.J.W., H.J.R. Lenders, R.S.E.W. Leuven, G. de Blust, N. Geilen, B. Goldschmidt, S. Muller, I. Poudevigne, P.H. Nienhuis (2004) BIO-SAFE: assessing the impacts of physical reconstruction on protected and endangered species. River Research and Application, 20: 299-313.

Geerling, G., A.M.J. Ragas, R.S.E.W. Leuven, J.H. van den Berg, M. Breedveld, D. Liefhebber, A.J.M. Smits (2006) Succession and rejuvenation in floodplains along the River Allier (France). Hydrobiologia, 565: 71-86.

Kajak, Z. (1993) The Vistula River and its riverine zones. Hydrobiologia, 251: 149-157.

Lenders, H.J.R., R.S.E.W. Leuven, P.H. Nienhuis, R.J.W. de Nooij, S.A.M. van Rooij (2001) BIO-SAFE: a method for evaluation of biodiversity values on the basis of political and legal criteria. Landscape and Urban Planning, 55: 121-137.

Wozniak, M., R.S.E.W. Leuven, H.J.R. Lenders, T.J. Chmielewski, G.W, Geerling A.J.M. Smits (2009) Landscape change and biodiversity values of the Vistula river valley in Poland. Landscape and Urban Planning (submitted).

Authors Index

NCR Boards

NCR Supervisory Board

December 2008
prof. dr. H.J. de Vriend, chairman
Deltares
email: huib.devriend@deltares.nl

A.G. van Os, secretary
programming secretary NCR
email: ad.vanos@deltares.nl

dr. R. Allewijn
DG Rijkswaterstaat-WD
email: roeland.allewijn@rws.nl

dr. H. Middelkoop
Utrecht University
email: h.middelkoop@geo.uu.nl.

prof. dr. H.H.G. Savenije
Delft University of Technology
email: h.h.g.savenije@citg.tudelft.nl

prof. dr. A.J. Hendriks
University Nijmegen
email: a.j.hendriks@science.ru.nl

prof. dr. A.Y. Hoekstra
University Twente
email: a.y.hoekstra@ctw.utwente.nl

J. de Schutter
UNESCO-IHE Institute for Water Education
email: j.deschutter@unesco-ihe.org

prof. dr. W.P. Cofino
ALTERRA
email: wim.cofino@wur.nl

prof. dr. W.P. Cofino
University Wageningen
email: wim.cofino@wur.nl

NCR Programme Committee

December 2008
G. Blom, chairman
DG Rijkswaterstaat-WD
email: gerard.blom@rws.nl

A.G. van Os, secretary
programming secretary NCR
email: ad.vanos@deltares.nl

I.L. Ritsema
Deltares
Email: ipo.ritsema@deltares.nl

dr. E. Stouthamer
Utrecht University
email: e.stouthamer@geo.uu.nl.

prof. dr. N.C. van de Giesen
Delft University of Technology
email: n.c.vandegiesen@citg.tudelft.nl

dr. R. Leuven
University Nijmegen
email: r.leuven@science.ru.nl

dr. D.C.M. Augustijn
University Twente
Email: d.c.m.augustijn@ctw.utwente.nl

dr. A. Crosato
UNESCO-IHE Institute for Water Education
email: a.crosato@unesco-ihe.org

dr. H.P. Wolfert
ALTERRA
email: henk.wolfert@wur.nl

dr. T. Hoitink
University Wageningen
email: ton.hoitink@wur.nl

NCR Publications series

In this series the following publications were printed:

NCR-publication n°:

00-2000	"Delfstoffenwinning als motor voor rivierverruiming; kansen en bedreigingen", editors A.J.M. Smits & G.W. Geerling (in Dutch) (out of stock, but can be downloaded from the NCR Internet site)
01-2000	"NCR Programma, versie 1999 – 2000", editors R. Leuven & A.G. van Os (in Dutch)
02-2000	"NCR workshop, de weg van maatschappelijke vraag naar onderzoek", editors A.F. Wolters & E.C.L. Marteijn (in Dutch)
03-2001	"NCR dagen 2000, het begin van een nieuwe reeks", editors A.F. Wolters, C.J. Sloff & E.C.L. Marteijn (partly in Dutch)
04-2001	"Umbrella Program IRMA-SPONGE, Background, Scope and Methodology", editors A. Hooijer & A.G. van Os
05-2001	"Summary of NCR Programme, version 2001 – 2002", editor A.G. van Os (also downloadable from the NCR Internet site)
06-2001	"The Netherlands Centre for River studies, a co-operation of the major developers and users of expertise in the area of rivers", editors A.G. van Os & H. Middelkoop
07-2001	"NCR-days 2001, from sediment transport, morphology and ecology to river basin management", editors E. Stouthamer & A.G. van Os
08-2001	"Land van levende rivieren: De Gelderse Poort", Stichting Ark, ISSN 90 5011 150 5; € 27,50
09-2001	"Guidelines for rehabilitation and management of floodplains, ecology and safety combined", editors H.A.Wolters, M. Platteeuw & M.M.Schoor
10-2001	"Living with floods: resilience strategies for flood management and multiple land use in the river Rhine basin", editors M. Vis, F. Klijn & M. van Buuren
11-2001	"Development and application of BIO-SAFE, a policy and legislation based model for the assessment of impacts of flood prevention measures on biodiversity in river basins", authors R.J.W. de Nooij, D. Alard, G. de Blust, N. Geilen, B. Goldschmidt, V. Huesing, J.R. Lenders, R.S.E.W. Leuven, K. Lotterman, S. Muller, P.H. Nienhuis & I. Poudevigne
12-2001	"Extension of the Flood Forecasting Model FloRIJN", authors E. Sprokkereef, H. Buiteveld, M. Eberle & J. Kwadijk
13-2001	"Interactive Flood Management and Landscape Planning in River Systems: Development of a Decision Support System and analysis of retention options along the Lower Rhine river", authors R.M.J. Schielen, C.A. Bons, P.J.A. Gijsbers & W.C. Knol
13M-2001	"Interactive Flood Management and Landscape Planning in River Systems" - User Manual version 1.0.0
14-2001	"Cyclic floodplain rejuvenation: a new strategy based on floodplain measures for both flood risk management and enhancement of the biodiversity of the river Rhine", editor H. Duel
15-2001	"Intermeuse: the Meuse reconnected", authors N. Geilen, B. Pedroli, K. van Looij & L.Krebs, H. Jochems, S. van Rooij & Th. van der Sluis
16-2001	"Development of flood management strategies for the Rhine and Meuse basins in the context of integrated river management", authors M.B.A. van Asselt, H. Middelkoop, S.A. van 't Klooster, W.P.A. van Deursen, M. Haasnoot, J.C.J. Kwadijk, H. Buiteveld, G.P. Können, J. Rotmans, N. van Gemert & P. Valkering
17-2002	IRMA-SPONGE, "Towards Sustainable Flood Risk Management in the Rhine and Meuse River Basins", Proceedings of IRMA-SPONGE Final Working Conference, editors A.G. van Os & A. Hooijer

18-2002 IRMA-SPONGE, “Towards Sustainable Flood Risk Management in the Rhine and Meuse River Basins”, (incl. main results of the research project), editors A. Hooijer & A.G. van Os

18E-2002 IRMA-SPONGE, “Towards Sustainable Flood Risk Management in the Rhine and Meuse River Basins”, main results of the research project, editors A. Hooijer, F. Klijn, J.C.J. Kwadijk & B. Pedroli

18D-2002 IRMA-SPONGE, “Zu einem nachhaltigen Management des Hochwasserrisikos in den Einzugsgebieten von Rhein und Maas - die wichtigsten Ergebnisse”, editors A.Hooijer, F. Klijn, J.C.J. Kwadijk & B. Pedroli (in German)

18NL-2002 IRMA-SPONGE, “Naar een duurzaam hoogwater risico beheer voor het Rijn en Maas Stroomgebied”, De belangrijkste conclusies van het onderzoeksprogramma, editors A. Hooijer, F. Klijn, J. Kwadijk & B. Pedroli (in Dutch)

18F-2002 IRMA-SPONGE, “Vers une gestion durable des risques d’inondation dans les bassins versants du Rhin et de la Meuse”, editors A.Hooijer, F. Klijn, J. Kwadijk & B. Pedroli (in French)

19-2002 “Laseraltimetrie en Hydraulische Vegetatieruwheid van Uiterwaarden”, authors M.R. Ritzen & M.W. Straatsma (in Dutch)

20-2003 “NCR -days 2002, Current themes in Dutch river research”, editors R.S.E.W. Leuven, A.G. van Os & P.H. Nienhuis

21-2003 “Kansrijkdom voor rivierecotopen vanuit historisch-geomorfologisch perspectief - Rijntakken - Maas - Benedenrivieren”, authors H. Middelkoop, E. Stouthamer, M.M. Schoor, H.P. Wolfert & G.J. Maas (in Dutch)

22-2003 “Lowland River Rehabilitation 2003: an international conference addressing the opportunities and constraints, costs and benefits to rehabilitate natural dynamics, landscapes and biodiversity in large regulated lowland rivers. Programme, abstracts and participants. Wageningen, September 29 – October 2, 2003”, editors A.D. Buijse, R.S.E.W. Leuven & M. Greijdanus-Klaas

23-2004 “Om de toekomst van het rivierengebied”, gelegenheidsredactie N. Geilen, F. Klijn, S.A.M. van Rooij, C. Stegewerns en C.C. Vos; themanummer tijdschrift ‘Landschap’ n.a.v. een studiedag georganiseerd door WLO en NCR. WLO-secretariaat, Postbus 80123, 3508 TC Utrecht, email wlo@knag.nl

24-2004 “NCR days 2003, Dealing with Floods within Constraints”, editors N. Douben, A.G. van Os

25-2004 “Summary of NCR Programme, version 2004 - 2005”, editor A.G. van Os

26-2005 “NCR-days 2004, Research for managing rivers: present and future issues”, editors A. Makaske, H.P. Wolfert, A.G. van Os

27-2005 “Large European river system responses to global change and human activities - The Volga and Rhine Rivers, Department Physical Geography, Utrecht University / Faculty of Geography - Moscow State University / RIZA, Utrecht / Moscow / Arnhem, editor H. Middelkoop

28-2005 “Rehabilitating large regulated rivers, Lowland River Rehabilitation Conference, September 29 – October 2, 2003, Wageningen (the Netherlands)”, ARCHIF FüR HYDROBIOLOGIE, Suppl. Vol. 155, No. 1-4, editors A.D. Buijse, F. Klijn, R.S.E.W. Leuven, H. Middelkoop, F. Schiemer, J. Thorpe and H.P. Wolfert

29-2006 “NCR-Days 2005, Research on River Dynamics from geological to operational time scales”, editors H.J.T. Weerts, I.L. Ritsema and A.G. van Os

30-2006 “Summary of NCR Programme, version 2006-2007”, editor A.G. van Os

31-2007 “NCR-Days 2006”, editors D.C.M. Augustijn and A.G. van Os

32-2007 “NCR-Days 2007, a sustainable river system ?!”, editor A.G. van Os

33-2008 “NCR-Days 2008, 10 years NCR”, editors A.G. van Os and C.D. Erdbrink